1-1-1976

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SQUANTUM, MASS.

by

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Introduction. No small compact area in the Boston Area provides such a wide variety of geological phenomena for beginning and advanced students as does the roughly 15 acre peninsula of Squaw Head on the northwestern side of Squantum, a section of Quincy, Massachusetts. The lithology and stratigraphy, the structure, the geomorphology of the region, and the historical evolution of this unique area can serve to provide the basis for really extensive research. Because of wave action and the susceptibility of the lithologies and structures to rapid erosion, marked changes in the shoreline can be noted even within a decade. The author has spent no less than fifty days in the close study of this interesting area and continues to discover new phenomena with each visit. Some of the changes over the past 35 years will be noted.

Lithology and stratigraphy

There is no point at this juncture in dwelling on the earlier works dealing with Squaw Head. These have been adequately described and discussed in a separate paper in this guidebook. Rather, I should like to dwell on the total geology, as I see and interpret it. The pace and compass map which accompanies this paper will refer to 38 points around the Head where interesting geological phenomena can be noted.

The oldest rock unit is exposed on the northern shore. At very low tide, when previous wave and undertow action have cleaned the wave cut terrace, this rock unit can be seen as well bedded siltstone of an essentially varved type with alternating layers of red-violet and light greenish colors with average thicknesses of the layers varying from one to six millimeters. In the upper three to five meters of this sequence masses of ill-sorted heterogeneous lenses of rock occur, with the longest directions of the lenses being parallel to the strike of the beds in the region. The other major dimension of the lenses is presumably parallel to the dip of the bedding of the underlying varves. A large quartzite boulder now rests in a pocket in the siltstone in the northwest corner of the Head. When the author first saw this 50 centimeter boulder, it was completely enclosed in the siltstone, except for one small area of exposure. Wave action has released it from its matrix, but it still rests in esentially the same position as when I first observed it 35 years ago. The upper two to three meters of the siltstone shows either no stratification, or the stratification is obviously contorted, as at locality 14 shown on the map. Messy heterogeneous masses occur as distorted lenses in this area.

The stratigraphy is not completely consistent throughout the north shore area of the Head, but for the most part the next stratigraphic unit is a completely heterogeneous mass. Rounded boulders as much as one meter in diameter occur, but these are rare. Boulders which approach 50 centimeters are common. Yet, there are many smaller clasts, most of which are rounded, but some are subangular. At least seven different lithologies can be seen in these pebbles and boulders. The matrix is sufficiently fine grained to facilitate the development of excellent cleavage in the matrix, cleavage which is equally as good as that in the underlying siltstone. There is probably nothing distinctive about this heterogeneous rock which can of itself rigorously define its origin. Comparable textures could be produced by glaciation, by mountain slope retreat in an arid region, by landslides, or by subaqueous slumping conditions. Essentially, there is no distinctive fabric for any of these rock types. Therefore, only by <u>context mapping</u> can one hope to establish the probable origin of the lithology. If one considers the total lithology and stratigraphy, as I shall show here, one is led very convincingly to the conclusion that the unit is of glacial origin; and the term Squantum Tillite is very apt.

One of the stratigraphic phenomena which supports this conclusion is the presence of well bedded sand and pebble beds within the body of the tillite. At stations 8,9,10 on the map as well as at station 24 this bedding is well exposed. The bedding is apparently alluvial in origin. In some of the finer beds at 9 and 10, three to four centimeter clasts, some of which are quite angular, are anomalously present. These could be explained in terms of small ice rafts moving out over an outwash region, and the bedded sandstones, pebble conglomerates, and even boulder conglomerates are to be best explained in terms of a frontal ice retreat with outwash developing in the foreground on top of the previously deposited till. In the northeastern section of the Head the conglomerate lens is as much as six meters thick, and this conglomerate lens is a notable part of the stratigraphy as far to the southwest as the quarry in the middle of the high ground near the directional arrow on the map. The presence of a sandstone-conglomerate member in the tillite suggests an oscillating ice front.

Stratigraphically above the tillite is a section which I have labelled a transition zone with a thickness of as much as ten meters. Lenses of completely heterogeneous material lie here and there within bedded siltstone. The bedding of the siltstone is deformed around these lenses, and there can be little doubt that they are till drops from ice rafts or icebergs moving out into the lake in which the varved siltstone was being deposited. The hill slope from the <u>D</u> in the word <u>Head</u> on the map down to the southeastern shore is essentially a dip slope in this transition zone material. The distribution of the till "drops" is best seen at stations 32, 33, 34. That the upper siltstone is not a repeat of the lower siltstone by means of an overturned fold, which might be inferred from the presence of the "drop" lenses below and above the tillite, is indicated by the absence of the highly disturbed zone near the upper contact. The bedding is not at all disturbed near the upper contact, as it is along the north shore in the lower contact region.

The uppermost unit in the Head area is again a bedded siltstone with varved properties. The overall grain size is slightly coarser in this rock unit than it is in the lower siltstone.

Three four inch basaltic dikes are occasionally observable at stations 36, 37, and 38. These strike approximately east-west and are vertical. An eight foot basaltic dike, striking roughly north-south, can be seen at 19. It is badly faulted and is accompanied by a ten centimeter quartz vein.

Glacial till of probable Wisconsin age rests upon the tillite in several places along the western and northern shores. The juxtaposition of Pleistocene till and Carboniferous (?) tillite is of interest. Possibly of more interest is the presence of Pleistocene glacial striations and polish on the Carboniferous(?) tillite at station 21.

Structure

The basic structure of the Head is of rock units striking between N45E and N70E and dipping 22 to 55 degrees southeastward. Such a structure could, of course, represent one limb of a fold; but I prefer to visualize the structure as a tilted fault block or tilted margin of a fault block. Faults are extremely common throughout the Boston region and in the Squantum region, making the last suggestion quite possible.

Cleavage is very well developed in the siltstones, with spacing between the cleavage planes of less than one millimeter wherever the rock has been exposed for more than a few years. The strike of the cleavage parallels that of the bedding planes, that is N45E to N70E, but the dip is generally perpendicular to the bedding dips, roughly 60 degrees in a northwesterly direction. Cleavage is well developed in the matrix of the tillite and helps to distinguish between the tillite and the conglomerate; the latter contains no silt size or smaller fractions and shows no cleavage.

Jointing is abundant in the rocks. The attitude of the joints is variable. Some of the joints parallel the obvious faults that occur in the rocks. Diamond shaped fragments are commonly developed between oblique joints and serve as susceptible zones of attack by wave action. In fact, the tillite and siltstones are particularly subject to wave quarrying because of their cleavage, joints, faults, and, in the siltstones, the bedding planes.

Faults are very common in the rocks. These are particularly obvious on the north shore. Most of the smaller displacement faults have not been plotted on the map, but faults are shown at localities 11, 12, 13 and 19-31. The dip of the faults varies from 60 degrees to vertical. The strike approximates north-south. A fault breccia zone at least 5 meters wide at station 11 serves as an area of rapid cliff retreat under wave action. The fault at this locality has a horizontal displacement of about 80 feet and is a normal fault. The horizontal displacement at locality 19 may be as much as 180 feet. Most of the faults have a right lateral displacement, and the block at locality 19 has been pushed southward to dictate the form of the shoreline. Mylonite and silicified gouge are common along many of the faults. A basalt dike which is itself highly faulted occupies the fault at locality 19. This suggests that much of the faulting was developed during the diastrophic phase which was accompanied by basalt dike formation, perhaps the Triassic episode. Many of the faults are occupied by quartz veins, varying in thickness from one centimeter to 10 centimeters, suggesting that the faulting was the result of uplift and extension. Some of the quartz veins are open in the middle and reveal well developed cockscomb crystals.

One of the very interesting aspects of the structure is the presence of extension fractures in the pebbles of the tillite. Although the attitude of these extension fractures is somewhat variable, they are usually about at right angles to the cleavage and are, therefore, nearly parallel to the bedding planes. Pebbles and boulders which vary in size from 2 to 60 centimeters may show these extension fractures. Many of the fractures are partially to completely filled with later quartz. Thus, the pebbles are somewhat elongated in the plane of the cleavage, not by plastic flow but by rupture.

Geomorphology

The most impressive aspect of the geomorphology of the area is the presence of the wave cut terrace at the base of a pronounced sea cliff. The terrace is best developed on the siltstone lithology where it may be considerably wider than 30 meters as exposed at low tide level. The terrace is best seen immediately following a northeastern storm when the undertow power is adequate to completely remove the usual clay that covers the lower part of the terrace. After a very heavy storm the entire terrace to the base of the sea cliff may be well exposed, showing a steeper upper profile and flatter lower profile. The smoothness of the terrace across the siltstone in spite of its abundant cleavage is remarkable. At the northeastern and eastern sections of the Head, the terrace is developed upon tillite and conglomerate and is much less flat. In fact, the existence of the jutting peninsula at the northeastern section of the Head is entirely due to the greater resistance of the conglomerate member to wave planation. The sea cliff at the head of the terrace varies from three to 16 meters in height. A classical example of a wave cut notch can be seen at locality 22. It occurs in a bedded conglomerate area and appears to be a very fragile phenomenon. However, no change has been seen in its profile during the past 35 years. In the Boston University lantern slide files is a picture which shows a car of vintage, roughly 1908, standing near the wave cut notch. No perceptible difference between the present notch and that of seventy years ago can be noted.

The trace of the cliff line on the northern shore is about 15 degrees to the east of the strike of the beds. This deviation is due to the presence of a series of right lateral faults which carry the resistant tillites ever farther southward as one proceeds eastward along the shore. The morphological expression of the faults is very noticeable, with variable indentations in the shoreline occurring at every fault. In the region of locality 11, as shown on the map, I have seen the cliff line retreat at least ten meters in the past 35 years. This particular fault is bordered by a fault breccia zone which is several meters in thickness.

The cliff line on the eastern shore to the south of the peninsula is shifted southward because of the 180 foot southward horizontal displacement of the tillite-lower siltstone contact. The cliff line recedes to the west on the eastern shore where the upper transition zone between the tillite and the upper siltstone occurs (station 32).

There are a series of terraces from sea level to the top of the hill in the midregion of the Head. The first terrace almost completely surrounds the head except for that area where the sea cliff of 16 meters has obliterated it. This lowest terrace lies at an elevation of three to four and one half meters.

A second terrace lies at an elevation of about 8 meters, and this terrace can be observed at several locations along the coast from Nantasket on the south to Marblehead on the north. In the Marblehead region this terrace is covered by Pleistocene glacial deposits which are presumably Wisconsin in age. Therefore the 8 meter terrace is preWisconsin and could well represent an interglacial still stand of sea level. Apparently, not much time is required to produce a terrace on these easily erodible rocks. The lower 4 meter terrace may well represent an oscillation of relative sea level in the past few thousand years, since clam shells have been found exposed in the soil lying on this terrace.

Steps in the topography can also be found at 13 meters and 20 meters. The top of the hill, which was certainly well glaciated during the Wisconsin ice invasion, lies at about 25 meters. This elevation is to be found at Nantasket and further north; and if this section of the coast is relatively stable, which it seems to be, the 25 meter level may well be the normal position of sea level during maximum deglaciation.

At locality 30, there is a mound of typical tillite surrounded by the 3 meter terrace. Just to the north of this former stack Wisconsin glacial striations and polish can be seen on the tillite. This clearly indicates that the plucking power of the glacier was relatively small. Capping the former stack is a smooth plane which is a remnant of the 8 meter terrace. Other stack-like masses inland toward the major hill also show this upper terrace level.

At low tide a beautiful spit extends from Thompson Island toward the head, and at the very lowest tides less than ten meters of water are exposed between the spit and the Head. This condition has been unchanged during the past 35 years; and it seems probable that this would-be tombolo is not going to join up with the head, due to the tidal currents which flow through the area in both directions with the shifting tides. The spit, however, has grown in elevation; and vegetation of salt water sedges has developed quite rapidly in the past 15 years. A major storm could reverse the process or even close the gap and allow a tombolo to form.

Geologic History

The geologic setting for the Squantum geology begins with the Acadian transformation of the Acadian geosyncline into a positively moving area. The usual history of a geosyncline as it moves from a negatively sinking area into a positively rising one is the uplift of a series of fault block mountains along steep angled reverse faults with the concomitant development of intermontane basins between the uplifting blocks. The Boston Basin region was one of these basins which probably developed at the close of the Devonian or very early in the Carboniferous. The evidence at hand suggests a major mountain block to the southeast of the Boston Basin with a wide intermontane basin to the north. A lake developed within this basin. Alluvial fans extended down from the mountain block into the basin, and these sediments interfingered with the simultaneously developing lacustrine sediments of the basin. The basic environment for the Roxbury conglomerate and Cambridge shale was thus set. The abundance of lithologies in the pebbles of the Roxbury Conglomerate suggests extensive alpine glaciation in the mountain block.

This suggestion is born out by the existence of the Squantum Tillite, the principle lithology at the head. A piedmont glacier began to move out over the gravel deposits. When the nose of the glacier reached the lake, icebergs carrying till and boulders floated out into the lake and dropped their loads on the lake deposits, as indicated by the boulders and messy lenses in the upper part of the lower siltstone. The glacier moved farther out into the lake. Occasionally, streams from the glacier would wash stratified materials into the lake, but soon the mass of the ice moved in over the lacustrine deposits and dropped materials and completely deformed them as indicated by the disappearance of bedding planes and the churned sediments at locality 14. After the glacier had stayed in the lake region for some time, the ice front receded, and streams once more moved out and deposited stratified materials of sand and conglomerate over the tillite. Once again the ice advanced, leaving several tens of meters more of till. As the ice withdrew from the region, icebergs once more carried till masses out and dropped them in the accumulating clays, forming the upper transition zone. The ice finally disappeared, and lacustrine deposits became dominant.

Faulting and dike intrusion may have taken place in the Triassic, and the Head sector probably was tilted about this time, developing the cleavage, extension fractures, and tilted bedding in one operation.

Wisconsin ice moved into the region and polished and striated the rocks, but some time before this four still stands of the ocean at levels of 3, 8, 13, 20 and 25 meters produced terraces in the easily erodible rock.

<u>The Geology of Salient Points Around the Head</u>

Locality 1. A 10 cm quartz vein, sometimes showing cockscomb, arrangement of quartz crystals, occupies a fault plane. Prominent shearing parallel to the fault walls is evidenced by the abundant cleavage in the adjacent tillite. A birch tree which now hangs from the side of the cliff was formerly well implanted on the 8 meter terrace just twenty years ago, indicating the rapid retreat of the cliff, even on this sheltered shoreline. Fault trends N85W and is vertical.

Locality 2. Another 10 cm quartz vein occupies a highly brecciated fault zone with well-defined mylonite defined in one section of the fault zone. Trend of the dike is N68W, and the fault is vertical.

Locality 3. Third fault showing indurated gouge layer 6 mm thick. Attitude of fault is N70W with 78 degree dip to north.

Locality 4. Interesting locality showing juxtaposition of Pleistocene till on Carboniferous (?) tillite. Note the comparable textures.

Locality 5. Very clean, planar jointing cuts through cobbles in tillite, indicating that jointing is post induration. If the tide is low, note the wave cut terrace which extends 70 meters outward from the cliff line.

Locality 6. Isolated two meter stack at high tide. A 50 cm boulder lies free in the midst of this lower siltstone outcrop. Thirty-five years ago, this boulder was just barely visible within the unbedded siltstone. Position of boulder suggests ice rafting from the approaching glacier which was moving into the lake.

Locality 7. Fault with attitude: N58W, 81°SW. The contact between a very messy tillite and disturbed siltstone can be seen here which probably represents contact disturbance between in moving glacier with its deposits and the underlying siltstone.

Locality 8. Good exposure of contact between tillite and siltstone. Several large tabular masses of iceberg dropped masses of heterogeneous material in siltstone. Contact attitude: N67E, 35°SE.

Locality 9. Well bedded stream deposited siltstone and sandstone showing small ice rafted pebbles; oscillating ice front withdrew and permitted some fluvioglacial activity and deposition.

Locality 10. Cast of large boulder in tillite; many such boulders have been removed by wave action during the past 35 years, and most of them have disappeared from the terrace by strong undertow action during heavy storms. Many of the pebbles and boulders show extension fracture cleavage which is roughly perpendicular to the cleavage in the tillite and parallel to the bedding planes in the adjacent siltstone. Beginning of fault zone with extreme brecciation through a breadth of about 16 meters.

Locality 11. Normal fault, N6E, 65°W. Right lateral displacement of contact between siltstone and tillite is roughly 80 feet.

Locality 12. Typical exposure of disturbed siltstone above well bedded siltstone, presumably produced by the advance of the glacial ice over the sediments of the lake bed. Marine terrace on the bedded siltstone extends more than 40 meters out to the position of low tide.

Locality 13. Another right lateral fault with silicified gouge. Shore becomes indented southward on the eastern side of the fault. Note the offset of the disturbed zone of the siltstone southward on the eastern block.

Locality 14. Excellent exposure of rolled beds of the upper siltstone. As the ice moved into this particular section of the lake bottom, the bedding planes were not destroyed, but they were severely deformed and rolled.

Locality 15. At this site there are some large masses of tillite at the base of the sea cliff. 35 years ago there was a large mass of rock attached to the cliff here except for one large joint. During one storm the entire mass was lifted and dropped perhaps 20 cm, but it was still resting against the wall. Through the succeeding years and storms the block has fragmented and the 4m X 4m X 1m block has been reduced to the present small residual blocks. Notice remnant of the 4m terrace above the sea cliff here. Just to the west, the sea cliff rises to an elevation of roughly 16 meters, and the lower terrace is obliterated.

Locality 16. The projecting cliff line here has retreated 8 m in the past 25 years. The excellent cleavage in the tillite plus faulting make the rock particularly susceptible to wave quarrying.

Locality 17. The deep recess or cave in this section is developing along a fault. The bottom sediments in this cave vary with each visit to the Head.

Locality 18. Sandstone bed here of ill sorted coarse sand grains formed during a recession of the ice front. It is a part of the rather extensive sandstone-conglomerate member which occurs in the tillite. Attitude: N45E, 38°SE.

Locality 19. Right lateral fault with a horizontal displacement of roughly 50 m is occupied by a messy basalt dike. The dike is itself faulted extensively, and a 10 cm quartz vein has occupied a part of the dike where later faulting took place. Just to the east about 10 m is a sandstone layer comparable to that at locality 18. Extending the two separated parts of this sandstone gives the approximate horizontal displacement of the fault. The 75 meter section east of the fault is displaced southward, but to the east of this block the rocks of the actual head are roughly on strike with the block to the west of the fault.

Locality 20. Very messy disturbed tillite and siltstone which was ostensibly formed at the interface between the inmoving glacier and the lake sediments.

Locality 21. Very interesting example of Pleistocene glacial polish and striations on Carboniferous (?) tillite. Glacier was moving S26E here; yet it was incompetent to move the isolated small stack like mass which stands above the 4 m terrace just 35 m to the south.

Locality 22. Classical example of a wave cut notch. From evidence at hand the general profile of this notch has not changed perceptibly in the past 70 years. The notch is incised in a messy conglomerate, rather than in tillite, which gives it greater resistance to wave destruction.

Locality 23. At low tide, wave cut terrace extends to narrow gut of water which separates Squaw Head from the spit which extends toward Squantum from Thompson Island. The channel is kept free of sediment by tidal currents which move in and out of the bay to the west. Mussel banks are growing steadily outward, and perhaps the spit will become a tombolo under very favorable circumstances.

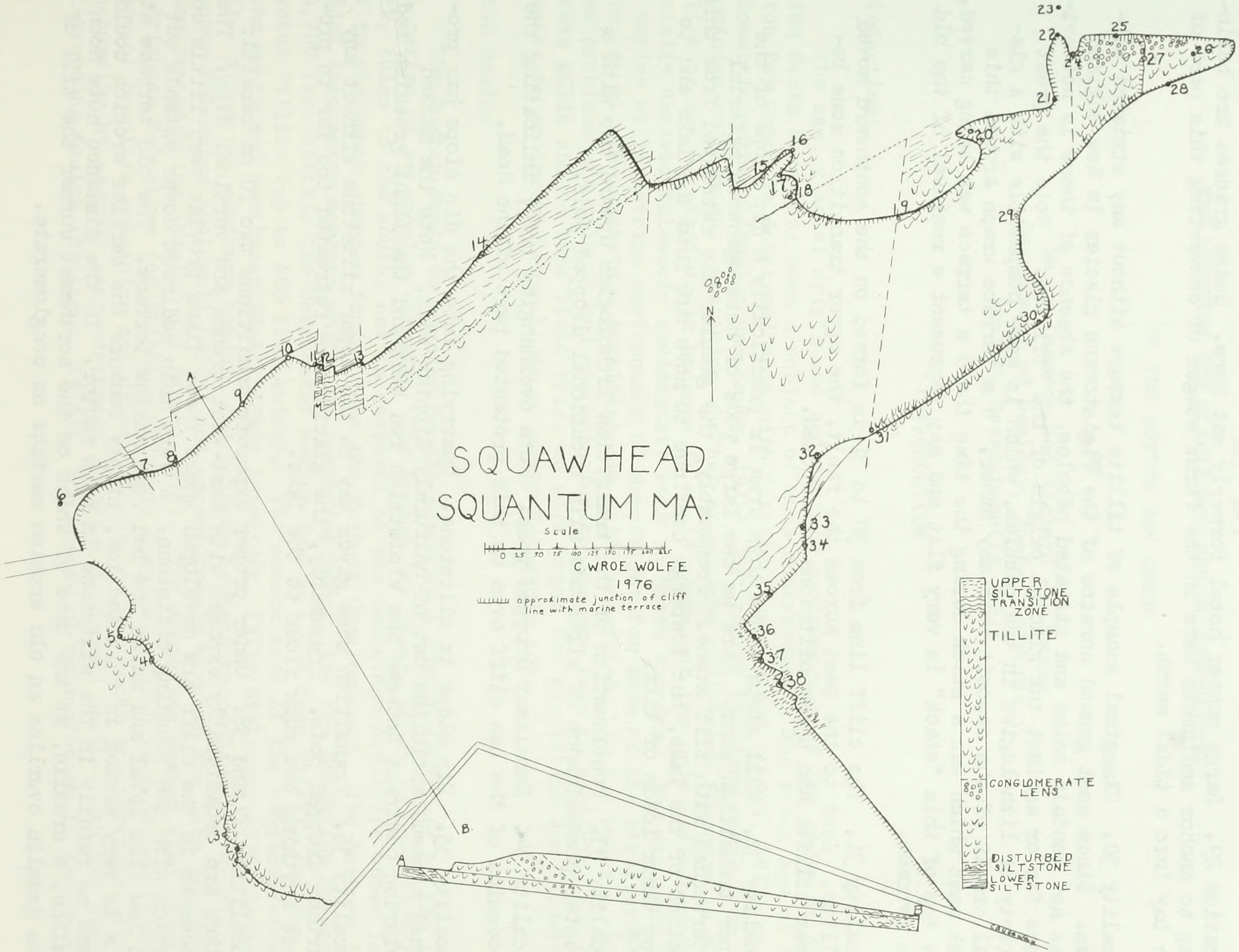
Locality 24. Excellent exposure of well bedded pebble stone and cobble stone conglomerates. Cave at this point has been etched out along the fault which goes from one side of the head to the other.

Locality 25. Tremendous 1 m boulder in conglomerate, possibly explainable in terms of ice rafting on a proglacial stream. 4 m terrace surrounds about 2/3 of the Head which owes its existence to the conglomerate member.

Locality 26. Peninsula exists at this point because of the much greater resistance of the conglomerate member to the action of waves.

Locality 27. Large block bounded by joints has stood in this attitude without much change in position for the past 35 years. An exceedingly heavy storm could dislodge it, but such has not happened during the three and one half decades of observation.

Locality 28. Large masses of granite in tillite or conglomerate. Distinction is very difficult here. If the matrix is conglomerate the boulders must have been ice rafted to this spot.


SQUAW HEAD
SQUANTUM MA.
Scale
0 25 50 75 100 125 150 175 200 225
C WROE WOLFE
1976
approximate junction of cliff line with marine terrace
N
UPPER SILTSTONE
TRANSITION ZONE
TILLITE
CONGLOMERATE LENS
DISTURBED SILTSTONE
LOWER SILTSTONE
A
B

Location 29. Large summer hotel formerly sat here. Sedge grasses are beginning to anchor sediments here in the first stages of converting this part of the bay into a tidal marsh.

Locality 30. Classical example of tillite texture without any striated pebbles. Since most ground moraine of the Pleistocene glacier in New England does not contain soled and striated pebbles, the absence of these is not evidence for or against the glacial origin of the "tillite." Note the great variety of lithologies in the pebbles, which is more compatible with a glacial origin of the deposit than any other. 4 m terrace wraps around this rock mass which was a stack during the time the 4 m terrace was being carved. The top of this "stack" is very flat and may represent a residual of the old 8 m terrace.

Locality 31. The cliff line from 30 to 31 is formed on the southward moved tillite. Just to the west across the fault, the upper transition zone between tillite and upper siltstone is exposed.

Locality 32. Hill slope above this area is practically a dip slope of the upper transition zone. Here we see large pods of heterogeneous material interbedded with silt stone. Presumably, the glacier has retreated from this section of the lake, but icebergs continue to move out into the lake and to drop their loads of till.

Locality 33. Continuation of the transition lithologies upward but with a greater predominance of siltstone with occasional dropped pods.

Locality 34. Excellent dropped pods. Note overhanging tree, indicating the recession of the sea cliff even on this protected part of the Head.

Locality 35. Dip slope in siltstone. Quarrying into the dip slope has produced a pseudoanticline out of uniformly dipping beds. Note the marked coloring contrast between the violettish red beds and the light greenish beds.

Locality 36. Transition zone gives way to the upper siltstone without any further dropped pods. Presumably, the glacier has retreated too far to provide anything but rock flour to the lake.

Localities 37 and 38. Under proper exposure conditions two 10 cm basaltic dikes are occasionally exposed with east-west trends and vertical dips. The recesses in the cliff are developed where these dikes provide very little cohesion with the bounding siltstone. A very thin sediment cover extends out to low tide level and masks the bed rock marine terrace. The old terrace at 4 m is very marked in this section, simply because the earlier erosion could work so readily in the siltstone in this sector. In the distance note Moon Island, a drumlin, at the base of which on the northeast corner the till of the drumlin overlies an old erosion surface on conglomerate.