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Rock lithology and glacial transport southeast of Boston

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ROCK LITHOLOGY AND GLACIAL TRANSPORT SOUTHEAST OF BOSTON

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Introduction

The purpose of this field trip is to examine some of the rocks in the southern part of the Boston Basin and the "granites" south of the basin. South of the granites there are no coastal exposures of any bedrock until south of Cape Cod.

The boulders found in the cliffs and drumlins and on the beaches from Scituate to Cape Cod reflect the unique lithologies of the rocks to the North and West. By tracing these lithologies the minimum distances of glacial transport of these boulders can be established. In addition, by examining the lithology of the cobbles and pebbles on the local beaches, minimum transport of ice and waves can be ascrtained.

Since the tide is the controlling factor for this field trip participants should plan on leaving Danvers by 7 a.m.

Regional Geology

The Boston Basin is a low lying structurally complex synclinorium bounded on three sides by thrust faults. The Boston Bay Group includes most of the bedrock found in the Boston Basin. A good description of the rocks in the Boston area is given by Billings (1976, 1982) on whom the following is based. Usually, the Boston Bay Group is divided into two formations, the Cambridge Argillite which is coeval and partly overlies the Roxbury Conglomerate. The Roxbury Conglomerate has been divided into three units which are, in ascending order, the Brookline Member, the Dorchester Member and the Squantum Member (Emerson, 1917, La Forge, 1932). The Brookline member has a maximum thickness of 4300 ft but thins rapidly to less than 500 feet at the southern end of the basin. The clasts in the Brookline Member are predominantly quartzite, quartz monzonite, granite and felsite. The pebbles are well rounded and range in size from one to fifteen centimeters in size. The matrix is a gray feldspathic fine to medium grained sandstone. The color can range from white to pink to red. Interbedded in the Conglomerate are also argillites. These argillites are really siltstones or mudstones. They are laminated (0.05-0.4")(0.13-1.02cm) but do not possess the papery or platy splitting characteristics of shales. They do however, split into flags or slabs (0.4-24") (1-60cm) thick. The argillite is typically red, pink or gray-green. The Brookline member of the Roxbury Conglomerate averages 60 percent conglomerate, 20 percent sandstone and 20 percent argillite.

The Dorchester Member of the Roxbury is very similar to the Brookline Member except that the percentages are different. The Dorchester Member is 15 percent conglomerate, 25 percent sandstone and 60 percent argillite. There are also some purplish gray and

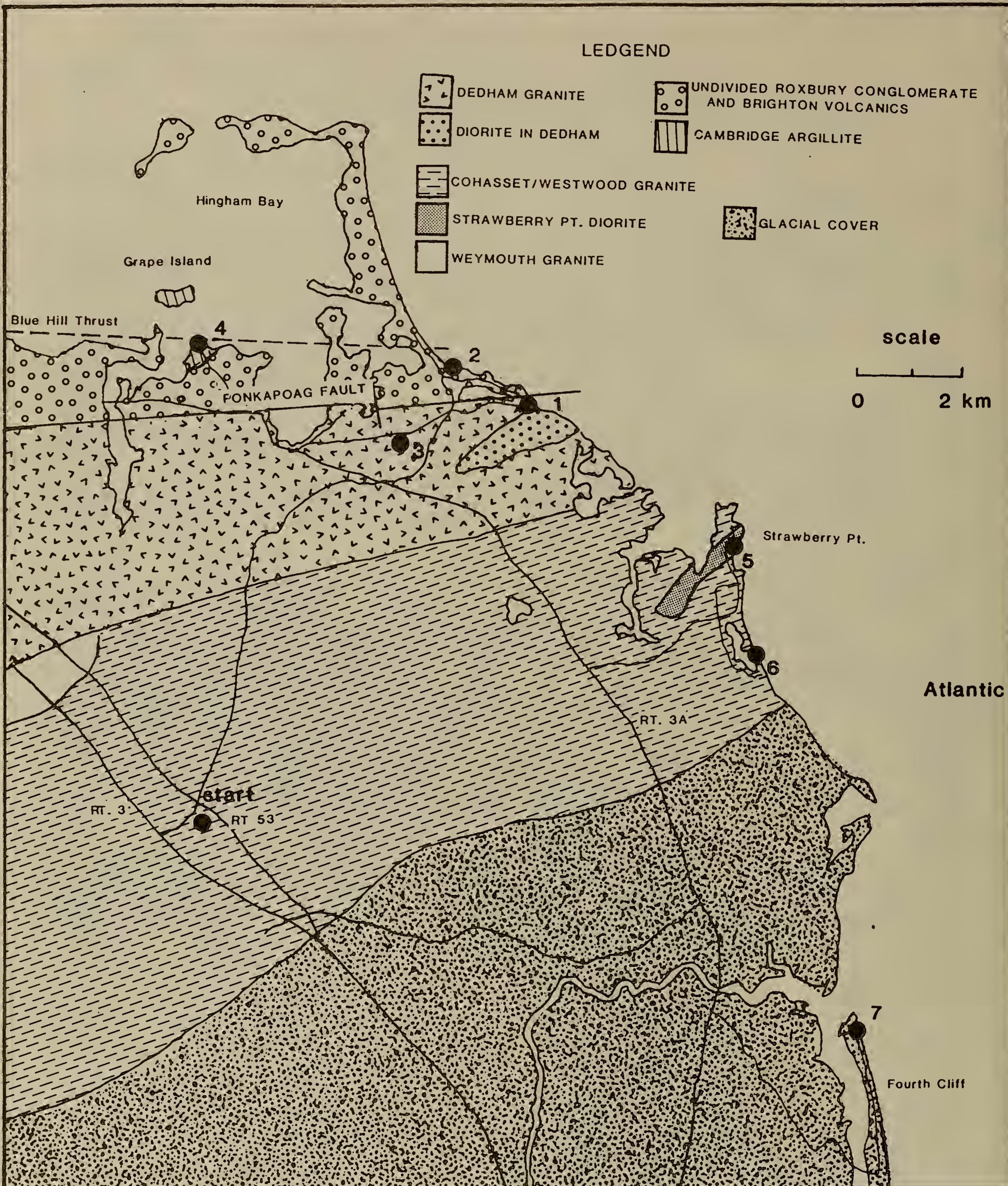
LEDGEND
DEDHAM GRANITE
DIORITE IN DEDHAM
UNDIVIDED ROXBURY CONGLOMERATE AND BRIGHTON VOLCANICS
CAMBRIDGE ARGILLITE
COHASSET/WESTWOOD GRANITE
STRAWBERRY PT. DIORITE
GLACIAL COVER
WEYMOUTH GRANITE
Hingham Bay
Grape Island
Blue Hill Thrust
PONKAPOAG FAULT
scale
0
2 km
Strawberry Pt.
Atlantic
RT. 3A
start
RT. 3
RT 53
Fourth Cliff
1
2
3
4
5
6
7

FIGURE 1

greenish gray colors present in the argillite. The Dorchester Member is about 1000 ft thick.

The Squantum Member is only between 70 to 400 ft thick. Many geologists consider the Squantum a tillite. It has subrounded to angular clasts from two inches to three feet in size of granite, quartz monzonite, quarzite, felsite and "melaphyre".

The Cambridge Argillite is never well exposed. It consists almost exclusively of gray argillite in which the beds range in thickness from 0.05 to 3 inches. The differences in their gray color is grain size dependent. The larger the size, coarse silt to fine sand, the lighter gray the color. The smaller the size, clay and fine silt, the darker is the gray color. Graded bedding is rare in the argillites. Many of the beds show a rhythmic layering due to the alteration of lighter and darker colors.

Within the Cambridge Argillite is a hard, white sericitic quartizte which is 400-500 ft thick. This has been named "Milton Quartzite" by Billings in 1929. The quartzite is visible for about two miles in Quincy.

The Boston Bay Group has recently been dated as Proterozoic Z, the late Precambrian, by microfossils from the Cambridge Argillite located north of Harvard Sqaure. (Lenk and others, 1982).

Scattered throughout the Boston Basin are the Mattapan/Brighton Volcanics. These are hard, dense white, pink, and red rhyolites. Also included are "melaphyres" (which are altered basalts and andesites) which are dark to light green and are composed chiefly of secondary minerals albite, hornblende chlorite and epidote. Recently Kaye and Zartman (1980) obtained a Pb-U date of 602 +/- 3 m.y. from analysis of zircon.

The Dedham Granite underlies most of the area south of the basin which is separated by the Ponkapoag Fault (see figure 1). This unit is more of a cartographic unit than a lithologic one (La Forge, 1932). It includes several "minor" units that Emerson thought were related to the Dedham. In the past thirty years, various attempts have been made to distinguish these other varieties from the Dedham. Chute (1966) describes the Westwood Granite as a younger, fine grained granite that intruded the Dedham; also a variety of ages has been reported from various localities in the unit, leading some to speculate as to whether or not there is more than one rock type present here (Zartman and Naylor, 1984).

To answer this question we have begun detailed chemical and petrological analysis in the Cohasset-Hingham area. This initial work indicates that there may be more than one magmatic series within the Dedham and that these units may be of different ages.

In the Cohasset area the "typical" Dedham Granite extends from the Ponkapoag Fault south appoximately four miles, where it comes in contact with a second type of granite. This contact is located somewhere within an extensive mylonite zone which parallels the Ponkapoag Fault Zone. The actual contact between these two granites has not yet been located. The Dedham Granite defined by Emerson (1917), is a coarse biotite granodiorite, light greenish white to dark grey, sometimes pink where microcline is plentiful. The quartz is vitreous and stained pale green. In

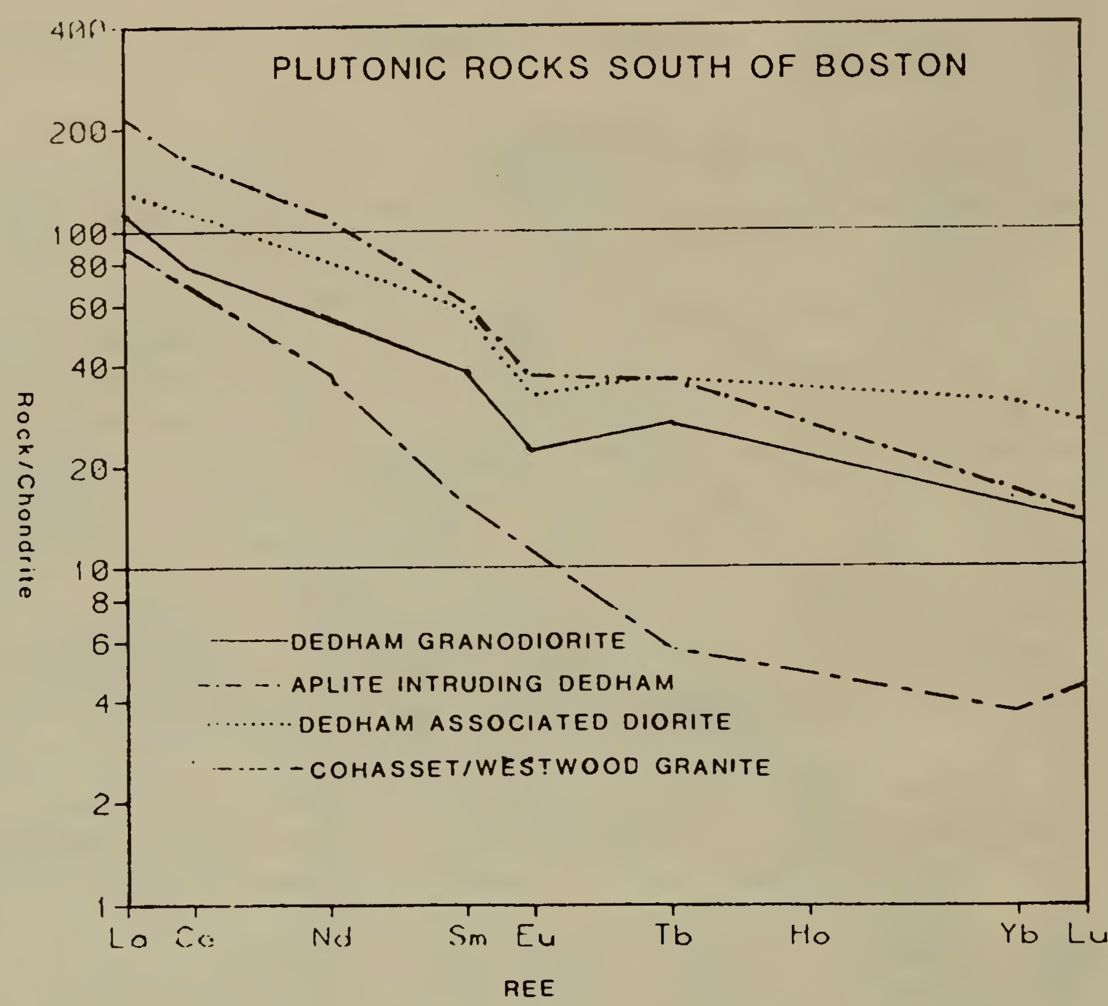

FIGURE 2

Major Elements of the Dedham and the Cohasset/Westwood Granites

	Dedham			Coh./Westwood	
	PD-1	PD-8	PD-7	PD-10	PD-4
SiO_2	66.48	58.57	60.21	71.80	55.63
TiO_2	0.58	1.21	0.34	0.34	1.56
Al_2O_2	15.74	17.36	18.84	14.56	15.13
Fe_2O_3*	4.55	7.51	6.82	2.17	9.48
MnO	0.14	0.19	0.16	0.07	0.18
MgO	1.08	2.54	0.36	0.93	3.76
CaO	3.16	5.90	1.65	2.29	6.65
Na_2O	4.57	4.72	7.22	4.43	4.01
K_2O	3.12	1.54	4.10	3.11	2.17
P_2O_5	0.19	0.44	0.22	0.11	0.87
Total	99.61	99.97	99.93	99.79	99.45

Table 1. PD-1 is from Courthouse Quarry, representing the porphyritic phase of the Dedham; PD-8 is from Black Rock Beach and may represent the parental phase of the Dedham; PD-7 is grey aplite injected into the Dedham; PD-10 is average Cohasset/Westwood; PD-4 is Strawberry Pt. Quartz Diorite, associated with the Cohasset/Westwood Granite. Analysis was done by XRF at the University of Massachusetts.

*Total Fe as Fe_2O_3.

some places it is foliated or banded, in others it is porphyritic with phenocrysts of microcline up to two inches long. The Dedham is composed essentially of microcline (perthite), andesine, quartz, chlorite, and epidote. The most recent date for the Dedham (Zartman and Naylor, 1984) is one of 630+/-15m.y., by U-Th-Pb analysis.

The Dedham Granite is well represented in the Cohasset area. It is mostly the porphyritic granodiorite with large phenocrysts of pink microcline. Locally there is a dark green dioritic variety, which appears to be the parent rock to the granodiorite. Mineralogically and geochemically it seems to be calc-alkalic (see Table 1). The second granite is located south of the mylonite zone and for convenience has been named the Cohasset Granite. Also, because of the chemical similarity to the finer grained Westwood granite to the west, it will be referred to as the Cohasset/Westwood Granite. This granite appears to have been formed under different conditions than the Dedham Granite as it lacks a Europium anomaly and is depleted in the heavy REE (see Figure 2). It is a pink, finer grained granite with subhedral quartz grains and is less altered than the Dedham. It is composed of microcline (perthite), oligoclase, quartz, hornblende and epidote. Chemically it is a true granite (see Table 1).

The diorite (Strawberry Point Diorite) associated with the Cohasset is found only at Strawberry Point in Situate (see Figure 1). It is composed of zoned plagioclase, hornblende, chlorite, quartz, microcline and biotite. It may be comagmatic with the Cohasset/Westwood, but the relationship is still uncertain.

A third granite is exposed in the Hingham area (see Figure 1), referred to locally as the Weymouth Granite. It is a foliated biotite granite composed of 30-60% plagioclase altered to sericite, epidote and albite; 10-35% K-Spar; 5% secondary biotite. Chute (1965) believed this granite intruded the Westwood Granite (Brenninkmeyer, 1976). Its magmatic relationship to the other two granites in the area is not yet known.

Glacial History

The Pleistocene deposits in the Boston area are surprisingly poor in till and rich in outwash deposits. The Boston area seems to have been located at the margin of two major ice lobes. The direction of ice flow varies from southwest to east through an arc of 135 degrees. However, the flow directions can be divided into four separate groups (Kaye, 1976). These range in approximate order of occurence: A. Lobate, spreading to south and east (Back Bay Readvance), B. South (Beacon Hill Advance), C. Southwest, D. South and southwesterly (mainly 32, 22 and 16 degrees), E. Easterly and southeasterly (variable 80 to 38 degrees). The oldest of the glacial indicators, the deep wide grooves, are easterly.

Many of the drumlin axes show the same range in orientation. In several places the long axis of the drumlin diverges from the striations exposed in the bedrock beneath them. Moreover, although there are many classically shaped drumlins, there are many that are round in plan, as well as compound, curved and sigmoidal shapes.

Road Log

From Danvers follow Rt. 128 south. At the intersection of Rt. 128 and Rt. 3 follow Rt. 3 south to exit 14, Rt. 228, which is the Rockland-Nantasket exit.

Cummulative Milage	Interval Milage	
0.0	0.0	At the bottom of the ramp turn left (228 N) towards Hingham-Nantasket.
0.8	0.8	Assemble in the Star Market parking lot at 8 A.M.
0.9	0.1	Get back on 228 and cross the intersection of Rt. 53.
4.6	3.9	228 takes a sharp right, follow the signs
5.1	0.5	Bear right at the fork.
5.4	0.3	Bear to the left leaving the Hingham Library to your right.
6.5	1.1	Cross the intersection of Rt. 228 and Rt. 3A.
6.8	0.3	At the intersection of Rt. 228 and East St follow the signs for 228, leaving Glastonbury Monestary to your left.
8.0	1.2	At the intersection of 228 and Jerusalem Rd., 500 ft. past "With Richards" restaurant, turn right onto Jerusalem Rd. Notice the sharp rise in elevation to the right caused by the upthrow of the Ponkapoag Fault
9.0	1.0	Turn left into Wadleigh Park Rd. and stop. Walk across Forest Ave Extension to Black Rock Beach.

Stop 1: Blackrock Beach/Green Hill

At low tide two phases of the Dedham Granite are exposed in a wave polished outcrop, fifty feet to the north of the main exposure. The first phase is a dark green, medium grained diorite, composed of plagioclase, microcline, hornblende, chlorite, quartz and minor sphene and magnetite. There are a number of xenoliths of fine grained diorite ranging in size from 10 to 30 cm. The second is porphyritic Dedham Granodiorite. This second phase is the same as at Stop 3, while the diorite is only present locally. Both phases have been foliated, giving them a banded appearance. This foliation generally strikes N20W, which is perpendicular to the local faulting. The major element and REE patterns (See Table 1, Figure 2) indicate that they may have been generated from the same magmatic series. It is also a possibility that the diorite is the parent of the granodiorite, if hornblende was a residual phase during fractionation, which the REE patterns seem to indicate.

Continuing north on the beach towards Green Hill, we cross the Ponkapoag Fault zone and enter the Boston Basin. The fault is orientated N 75 degrees East and dips 80 degrees north. Billings (1982) now believes that the Ponkapoag fault is an unrotated normal fault downthrown to the northwest. Notice the large boulders, up to 5 m in diameter, scattered in front of Green Hill, which is a drumlin. These boulders were eroded from the drumlin before the seawall was erected. Many of the boulders are Roxbury Conglomerate, and the porphyritic phase of the Dedham.

Pass the sea wall at Green Hill and continue North, approximately 500 m further. Along the beach is an outcrop of the Dorchester member of the Roxbury Conglomerate. There are no other exposures of the Roxbury from this point south. There are a number of clasts of weathered Dedham here. Many of them are added to the beach as the less resistant sandstone matrix is eroded away by wave action.

Cummulative Milage	Interval Milage	
10.3	1.3	At the ocean side of Wadleigh Park Rd. turn left onto Atlantic Ave. Follow it until it intersects Nantasket Ave. Turn right onto Nantasket Ave.
10.4	0.1	Turn right into the MDC parking lot as close to "On the Rocks", bar as possible. Walk onto beach and around the building.

Stop 2 Atlantic Hill

At the south end of Nantasket Beach is Atlantic Hill. Here a good cross section of the basal volcanic units of the Mattapan Volcanics and the Boston Bay Group Sediments are exposed. These units have been brought to the surface by the Blue Hills Thrust Fault (see figure 1). Atlantic Hill is on the very south east margin of the Boston Basin within the southern limb of a north east plunging anticline.

Just left of the bar "On the Rocks" is a hard dense greenish gray andesite lava about 18 m thick. These andesites are pillowed, as outlined by the lighter green epidote veins. They also contain bombs. Above the andesite is a 9 m bedded tuff (strike N65E, dip 25SE). This layer is a water lain ash deposit. In the upper part of this unit there are many coarse volcanic fragments. Above this are thin lenticular beds of andesite and tuff. The hill is capped by another greenish grey andesite lava. These andesites are deuterically altered. Plagioclase, chlorite and epidote are the major constituents plus accessory magnetite. There is little primary quartz, but quartz and calcite may be abundant as secondary minerals (Bell, 1964, Skehan, 1975).

Below the andesites and best exposed at low tide on Long Beach Rock is the sedimentary sequence of the Boston Bay Group. The lowest units, to be seen only at low tide on the north side of Long Beach Rock, are tuffaceous conglomerates and agglomerates which include fragments of the underlying Dedham Granodiorite and Lynn Volcanics and also arkose boulders. Above this are 45 cm thick beds of intercalated red sandstone and 15-30 cm layers of banded green porcelanous shale.These thin beds show brecciation and penecontemporaneous faulting and baking. The contact between the volcanics and the sediments can also be seen at this base of the cliff (around the corner from the bar).

The dikes, especially those on Long Beach rock are parallel to the local faulting and seem to be related to the volcanic activity that produced the andesite flows. The dikes predate the faulting (Crosby, 1893).

Return to Nantasket Ave. Turn left.

Cummulative Milage	Interval Milage	
10.7	0.3	Follow Nantasket Ave. (Rt. 228). Turn right.
10.9	0.2	Bear rght at the intersection of Rt. 228 and Rockland St., leaving the Mobil gas station to the left.
12.2	1.3	Follow Rockland St. until it intersects George Washington Blvd. Observe the large glacial erratic to the left enclosed in a small park. A plaque is embedded in one side, dedicating it to W.O Crosby and making the erroneous statement that it had been transported thousands of miles.
12.7	0.5	Turn right onto George Washington Blvd. and drive to the large parking lot located just past the Hingham District Court house. Pull into the far end of the lot and park near the overgrown dirt road. Walk down the road into the quarry.

Stop 3: Courthouse Quarry

The quarry shows the granodioritic phase of the Dedham which is the same green porphyritic rock, with large pink microcline phenocrysts described by Chute (1966), in North Abington. It is also the same as the second phase seen at Stop 1, except it is not foliated. It is composed of andesine, orthoclase, quartz, chlorite, sericite and minor amounts of hornblende, apatite, sphene, epidote, magnetite and flourite. The chlorite and epidote are probably alteration products of biotite and hornblende, as the rock has been extensively fractured. The fractures have also been filled with chlorite and epidote.

Nellis and Hellier(1976) note several different dike sets here, which are best exposed in the northwest wall of the quarry. One set is composed of dark green diabase and ranges in thickness from a few centimeters up to two meters. This set may be related to either the Brighton Volcanics, making them Precambrian, or to the Triassic dikes of the Conneticut Valley (Billings, 1976). It is also possible that some are Precambrian and some are Triassic; at this point there is no definite answer to this problem. The second set of dikes is aplitic. They range in color from pink to gray and from half a centimeter to 30 centimeters in thickness. This set is chemically similar to the wall rock (see Table 1, Figure 2) although the slight enrichment of the light REE may indicate a more evolved magma. In any case, it appears that this dike set originated from the same magma as the granodiorite and that the aplite was injected into the granodiorite while it was cooling.

Cummulative Milage	Interval Milage	
13.1	0.4	From the parking lot turn left onto Washington Blvd. Bear right onto Rockland St.
13.9	0.8	Follw Rockland St. to Hingham Rotary. Continue to follow Rt. 3A north.
15.6	1.7	Follow 3A leaving "Pages" restaurant to the left, through a stop light and around a sharp left turn, to the intersection of 3A and Downer Ave.
15.8	0.2	Turn right onto Downer Ave. and follow it to Planters Field Rd, across from the Foster School.
16.0	0.2	Turn left onto Planters Field Rd. and follow it to Wompatuck Rd.
16.1	0.1	Turn left onto Wompatuck Rd until you reach Kimball Beach Rd.
16.5	0.4	Turn left and follow Wompatuck Rd until it meets the ocean. Park and walk to the beach.

Stop 4 Cambridge Argillite

This stop can be reached only at low tide. The outcrop is exposed approximately 100 meters north of the end of te road. This is the only exposure of Cambridge Argillite in this area of the basin, although, it can also be found across the Bay on Grape Island and on some of the islands north of Nantasket. This exposure is typical of the Cambridge with alternating dark grey argillite and light gray siltstone, the beds strike N70E and dip 70S. Note the small beach above the outcrop is composed mainly of the argillite and the nearby volcanics, with only a small percentage of granite

Cummulative Milage	Interval Milage	
17.4	0.9	Return to 3A.
19.1	1.7	Turn left on 3A and drive south to the Hingham Rotary. Follow the signs for 3A South to Cohasset and Scituate.
24.7	5.6	Follow 3A south, through three stop lights, past a small shopping plaza on

		both sides of the road, followed by several car dealerships, to the exit for Minot and North Scituate.
25.2	0.5	Turn left onto Bailey Rd. and follow it until it intersects Country Way at a stop light.
26.7	1.5	Go straight through the lights, the road changes its name and now is Ganet Rd. Follow Ganet Rd bearing right at the fork until the intersection with Hatherley Rd.
27.0	0.3	Follow Ganet Rd. until it ends and then turn left onto Glades Rd.
27.8	0.8	Follow Glades Rd. until the gates of the Adams Estate. SPECIAL PERMISSION MUST BE OBTAINED BEFORE ENTERING.
28.0	0.2	Drive into the estate until you reach a small dirt path on the ocean side of the road.

Stop 5 Cohasset Granite and Strawberry Point Diorite

This stop requires about a half mile walk through somewhat rugged teraine. Excellent examples of both the Cohasset Granite and the Strawberry Point Diorite, can be seen here. Walk towards the ocean on the short dirt path into the abandoned quarry. The Cohasset here is a medium grained, pink to gray granite containing microcline (perthite), oligoclase, quartz, chlorite, hornblende, epidote, magnetite, apatite and sphene. The quartz is usually well formed in subhedral crystals and tend to be equigranular with the feldspars. In several spots, there are fine grained xenoliths of diorite, approximately 30 cm in diameter.

Walk north out of the quarry and along the shore. As you approach the contact with the diorite, the xenoliths become more common. About a thousand meters out of the quarry, the dioritic xenoliths become larger some up to two meters in diameter. The contact between the granite and the diorite is ten meters further north, just south of the gray house on the point. The diorite is composed of zoned plagioclase, hornblende, chlorite, quartz, microcline, biotite and sulfides. It has a dike like apperance in thin section and most of the unit has been hydrothermally altered. The contact here is sharp but neither margin is chilled.

Continiung north across the diorite, there are a number of large xenoliths of the Cohasset in the Diorite. At approximately 1500 m, there is a large xenolith of Cohasset (greater than one meter in length) that incorporates a xenolith of diorite (20 cm in diameter), this initial evidence seems to indicate that the two units were comagmatic, but wether they belong to the same magma series is still uncertain. Continue north to the contact with the Cohasset and then the short walk back to the cars along the road.

Cummulative Milage	Interval Milage	
28.5	0.5	Return through the gate and follow Glades Rd to the first road on the right (Baileys Causeway).
28.8	1.3	Follow Baileys Causeway until it intersects Hatherley Rd.
30.1	1.3	Turn left on Hatherley Rd. Go through the intersection with Garnet Rd. Follow Hatherley until you reach Mann Hill Rd.
30.1	0.2	Turn left onto Mann Hill Rd. and follow it to the intersection of Stanton lane. Pull off the road as far to the left as possible. We have to turn around at the bottom of the road.

Stop 6 Mann Hill Beach

Mann Hill Beach is a shingle bay mouth bar. At low tide a sand bar stretches across the entire length of the beach. The shingle reaches 10 m above low water and shows well developed imbrication, several berm lines and cusps. The pebbles and cobbles of the shingle are both size and shape sorted.

The sediments at Mann Hill ranges from fine sand to boulders over 30 cm in size. On the lower foreshore fine sand is dominant. On the middle foreshore, halfway between low and high tide, pebbles start to make their appearance. On the upper foreshore shingle is found. The average of all the shingle sizes, based on the 30,000 measurements of the largest diameter, is 4.3 cm. The average intermediate diameter is 3.14 cm, and the smallest diameter is 1.65 cm.

There is a gradual increase in size from the upper foreshore to the berm. The largest sizes are found at the berm. Generally, a decrease in size is found landward of the berm. If more than one berm is present, as is often the case, there is a small decrease in size just landward of the berm in the swale.

Along the beach there is a gradual increase of shingle size from north to south. In the north, the average size is 3.1 cm, while in the south it is 5.3 cm. The only places where there are local variations on this along beach increase in sediment size is within the cusps. Inside the cusp bays the coarsest sediment is found in the landward end and on the north side.

Shingle Lithology

There are eleven common lithologies found in the pebbles on Mann Hill Beach. As can be seen in table two, the most frequently found lithology are the granites. Three types of these are found. The most common is the foliated, light pinkish grey medium grained Dedham granodiorite, which has 25% quartz, 10% altered biotite and the remainder of the minerals sauseritized plagioclase and orthoclase. In the Dedham there are many xenoliths of two types of diorite and a fine grained amphibolite. Less commonly found is

Table 2 Shape differentiation between the thirteen common pebble and cobble lithologies at Mann Hill Beach.

	Blade	Ellip Plate	Ellipsoid	Needle	Plate	Short Rod	Sphere	Thick Blade	Thick Plate
Dedham	0	1	27	1	1	18	15	1	36
Cohasset-Westwood	0	1	25	1	1	17	16	2	36
Weymouth	0	0	31	2	3	15	10	1	38
Diorite in Dedham	0	2	35	1	6	10	7	2	37
Strawberry Pt Diorite	0	2	37	2	9	9	3	2	36
Mattapan Andesite	1	3	36	2	5	11	5	2	36
Amphibolite in Dedham	0	2	26	4	9	17	6	4	33
Basalt	1	6	34	2	8	10	3	3	33
Roxbury Conglomerate	1	5	17	1	9	11	6	6	42
Milton Quartzite	0	1	31	2	3	17	10	1	36
Mattapan Rhyolite	1	1	32	2	3	14	7	1	39
Cambridge Siltstone	1	10	36	1	13	5	2	7	25
Cambridge Sandstone	1	8	30	2	9	11	4	3	33

Table 3 Percentage Distribution of the Size in centimeters of the Different Lithologies of the thirteen common pebble and cobbles at Mann Hill Beach.

	1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10
Dedham	1	10	35	30	13	6	3	2	1	1	1
Coh./Westwood	1	17	39	23	11	5	2	1	1	1	0
Weymouth	1	13	28	28	14	7	3	4	2	1	0
Dio in Dedham	1	11	36	28	15	5	2	2	1	1	1
Straw. Pt Dio.	0	1	46	28	14	8	3	1	1	0	0
Mattapan And.	1	18	36	25	12	5	2	1	1	1	1
Amphi. in Dedham	2	19	35	20	13	6	4	2	0	0	0
Basalt	1	17	39	26	11	5	1	1	1	0	1
Roxbury Congl.	1	11	30	34	14	5	1	3	1	0	0
Milton Quartzite	1	18	40	23	10	5	3	1	0	1	1
Mattapan Rhy.	1	20	38	24	11	4	1	1	1	1	0
Cambridge Silts.	1	19	39	23	11	5	1	1	1	1	1
Cambridge Sands.	0	13	33	28	15	6	3	1	1	1	1

the Cohasset-Westwood granite. This granite is pinkish grey, fine to medium grained with 25-35% quartz, 10% microperthite and accessory apatite, sphene and magnetite (Chute, 1965). Even rarer is the Weymouth Granite, which is medium grey, foliated biotite granite composed of 30-60% plagioclase which is almost completely altered to sericite, epidote and albite, 10-35% orthoclase and microcline, and 5% olivine green biotite and large sodic plagioclase phenocrysts (Chute, 1965).

The siltstone is a greenish to brownish grey, fine grained, thin bedded argillite which contains quartz, sericite and opaque minerals (probably graphite) in a finer matrix too small to be identifiable. The siltstone probably belongs to the Boston Bay Group, specifically the Cambridge Argillite or possibly the Braintree Argillite.

The sandstone is obviously coarser, but has the same appearance as the argillite. It is not half as common as the argillite. The sandstone owes its origin to the Boston Bay Group in the Roxbury Conglomerate and Cambridge Argillite found only north of the Ponkapoag fault.

Both the rhyolite and andesite are part of the Mattapan/Brighton Volcanic Complex. The rhyolite is the most common rock found on Mann Hill. The rhyolite is predominantly red and purple, but may be brown tuffs and flows usually with small phenocrysts of quartz and microperthite. Most of the "rhyolite" is so fined grained it is probably a devitrified tuff. The andesite is the second most common lithology found on Mann Hill Beach. It is bluish to greenish grey with small phenocrysts of sericitized plagioclase, quartz and chlorite in groundmass of very fine plagioclase laths. Secondary epidote is common, giving the rock a greenish tinge.

Although only less than one percent of all the rocks on Mann Hill are recognizable as Roxbury Conglomerate, there should be many more. Many of the Dedham,andesite, rhyolite, quartzite and amphibolite pebbles are probably second generation, having first been present as pebbles in the Roxbury.

The basalt is a medium to dark grayish green, fine grained, massive rock. It frequently has subophitic texture. The basalt probably came from the diabase dikes so prevalent throughout the neighboring quadrangles to the northwest.

The first diorite is a medium to coarse grained massive dark rock, greenish-grey in color consisting predominantly of plagioclase which is almost completely altered to epidote, albite and sericite with lesser amounts of hornblende, a light pyroxene and olive green biotite. The second diorite is very similar except that it is much finer grained and even darker in color. The first diorite resembles the diorite within the Dedham. The second is a dead ringer for the Strawberry Point Diorite.

The quartzite is light grey to white, massive quartzite with minor quantities of biotite. It probably owes its origin to the "Milton Quartzite" of Billings (1929) or the quartzite pebbles in the Roxbury Conglomerate.

Least common of the rocks is the greyish green amphibolite in which the layers have fine alterations of felsic and mafic minerals producing a striped appearance. Hornblende and plagioclase are the principle components with minor amounts of chlorite, quartz, epidote, sphene and calcite. The amphibolite is common only as xenoliths in the Dedham granodiorite.

On Mann Hill Beach, all the lithologies are not admixed equally. There is more rhyolite and quartzite on the lower fringes of the shingle and more siltstone and andesite on top of the berm. What is remarkable is the size distribution of the different lithologies. Each lithology has virtually the same distribution of their intermediate axes (see table 3). The only one that is a tiny bit different is the finer grained Strawberry Point Diorite.

Shingle Shape

Anyone who has visited a shingled beach has seen the differences in the shape of the pebbles between those at mid tide and those at the top of the berm. A description of shape or geometric form involves several different but related concepts. On one side are the shape factors which depend on the relative lengths of the particle with respect to standard Cartesian coordinates. On the other hand is the sediment's angularity or roundness.

In 1935 Zingg showed that if the ratio of intermediate to the maximum lengths (B/A) of a pebble is plotted against the ratio of the shortest to the intermediate lengths (C/B), the particle may be classified according to its shape. Zingg utilized four shape classes. We have modified this to nine shapes, see figure 3.

The proportion of flat shapes at Mann Hill Beach is surprising, especially in view of the large proportion of non-layered rocks composed of equidimensional grains (granite, diorite, rhyolite and quartzite). However, the Boston Basin and surrounding areas are characterized by thrust faults, tear faults and normal faults. Especially in the southern part of the basin, the structure consists of numerous thrusted anticlines which constitute an imbricate block structure with minor thrusts and rock slices (Billings, 1929). Locally numerous shears are present, spaced at intervals between 1-100 cm apart. Moreover, two types of cleavage are prevalent. These ruptures are uniformly perpendicular to the bedding and to the imbricate blocks. Also nearly ubiquitous is a set of remarkably parallel joints spaced at intervals of 1 cm to 15 m. When two or three sets of joints are closely spaced, the rocks break into parallelopipeda 5-50 cm on a side (Billings, 1976). These, after being eroded by glacier ice and deposited in drumlins or outwash, are rounded by wave induced transport to form the flat shapes. The Wadell's (1933) operational sphericity follows the frequency of occurence pattern. The white area is bordered on the bottom by a sphericity of 0.5 on the bottom and by 0.9 on the top.

The distribution of the shapes is lithology dependent. The Cambridge Argillite has the most elliptical plates and the granites have the most spheres (see Table 2). The majority of the pebbles could not have been transported very far either by the ice or by waves. The remarkable similarity in size distribution shows there is relatively little abrasion and that the sizes are

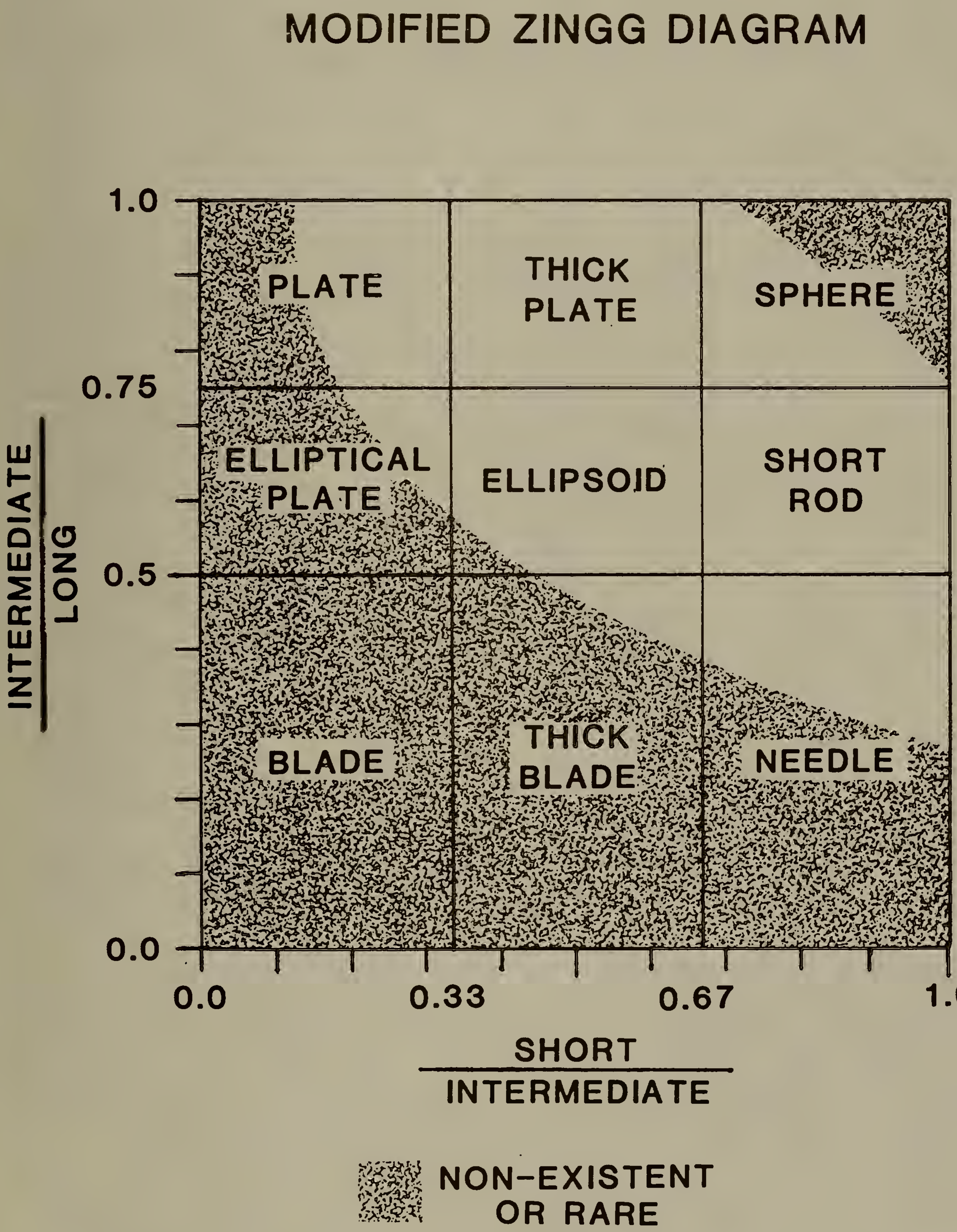
MODIFIED ZINGG DIAGRAM
1.0
0.75
0.5
0.0
INTERMEDIATE
LONG
PLATE
THICK PLATE
SPHERE
ELLIPTICAL PLATE
ELLIPSOID
SHORT ROD
BLADE
THICK BLADE
NEEDLE
0.0
0.33
0.67
1.0
SHORT
INTERMEDIATE
NON-EXISTENT OR RARE

FIGURE 3

inherited from the faulting and jointing.

In the over 30,000 measured and identified pebbles, we have never seen the distinctive grey to bluish grey Quincy Granite, nor the fine grained riebeckite granite (Chute, 1969), both of which are exposed 15 km to the northwest in between the Blue Hills Thrust and Ponkapoag Fault. The closest Mattapan Volcanics are exposed 7.5 km to the north. If the faults are extended out into the ocean the closest the Mattapan could be is 6 km. The farthest from the source are the Weymouth Granite pebbles, which came from 15 km due west.

Cummulative Milage	Interval Milage	
31.5	1.2	Return to the intersection of Ganet Rd. and Hatherley Rd.
33.4	1.9	Turn left onto Ganet Rd. and return to Rt. 3A.
38.3	4.9	Turn south on 3A. Cross the intersection of 3A and 123. After going over the North River Bridge, take the first left onto Summer St., to Hummerock and Fourth Cliff.
40.8	2.5	Follow Summer St., bearing left at the intersection with Prospect St., remain on Summer St Bear right at the fork with Damon Pt. Rd., continue to the intersection of Church Rd. and Summer St.
40.9	0.1	Turn left onto Elm St, bearing right at the fork of Elm and Ferrywell Sts., remaining on Elm.
41.0	0.1	Bear right at the fork of Peabody and Elm, remaining on Elm.
41.4	0.4	Turn left onto Sea St.
41.6	0.2	Go over the bridge and turn left onto Central Ave.
43.1	1.5	Follow Central Ave to River Rd. Park off the road and follow the boardwalk to the beach. Walk north.

Stop 7 Fourth Cliff

Fourth Cliff is a 24 m high, 0.8 km long drumlin. This is the most southerly of the over 150 drumlins of the Boston area. Fourth Cliff consists of 12.30 cm of soil and 9 m of brown oxidized gray till that contain some reed-like plant remains. These have been dated at 35,000 B.P. (Chute, 1965). The typical amount of silt and clay in the till is 19% with a maximum of 40%. This is an unusually low percentage for eastern Masachusetts drumlins.

On the east side of the drumlin two lenses of sand and gravel 3-4.5 m thick separated by 3 m of till crop out. These lenses dip 10 degrees to the south and appear to pinch out at the bottom of the cliff. The composition of the pebbles and cobbles in the till is primarily Dedham, Westwood and Weymouth Granites and Mattapan Volcanics. The Cambridge Argillite is no longer present in large quantities. The sand is 60% quartz, 20% feldspars and 20% heavy minerals such as biotite, magnetite, garnet and hornblende.

On the beach are many boulders and cobbles, some of which are so large that even storm waves have difficulty moving them. Among the largest boulders, two are the Cohasset-Westwood Granites, one is from the Diorite Dike at Strawberry Point in the Cohasset, three are Dedham Granites and one is a Roxbury Conglomerate. The glacial transport of these is 6 km from the SSW and 9 km to the SE; the diorite was transported a minimum of 8 km from the SSE. The closest Roxbury is 13 km away to the NNW. The Weymouth Granite was transported just over 15 to the SE. As you walk along, make sure that you see the large (1.2m) Dedham Granite boulder with the oriented xenoliths of amphibolite. On the northeast point there is a boulder pavement. It has an exposed width of 60-100 m at low tide. Of interest is that there seems to be little or no sand movements across this boulder platform below mid-tide level. The boulders below this level show little or no abrasion; instead they are covered with barnacles and seaweed and many show evidence of abrasion. There are few weathered surfaces or flora and fauna that could survive above mid-tide level. This scouring is caused by sand and shingle which is washed back and forth at the still stand of the high tide. Above the mid-tide level the shingle extends about 4km south of Fourth Cliff. Beyond this, the beach is composed entirely of sand.

Before the 1900's there existed a barrier between Third and Fourth Cliffs. The mouth of the North River was 4.8 km south of its present location. Then on November 27th, 1898, with a high tide of 4.5 m (1.3 m above normal) and a wind of 120-130 km/hr piling waves up even higher, the ocean cut through the beach ridge between the cliffs. In a few hours a channel 45 m wide and 3 m deep had been excavated. Now the channel is 120 m wide and 4.2-4.8 m deep. The average flood tidal velocity through the gap is 24 cm/sec. The ebb tide velocity is 36 cm/sec.

It took three years of longshore drifting to fill the old river entrance. The result is that the South River now flows further north and has developed a sand bar which extends into the North River which recurves it. The bar, now, is almost a reverse mirror image of Cape Cod.

The spit behind Fourth Cliff can be divided into two distinct parts. The first part is adjacent to the drumlin. It is fronted by a low scarp 60 cm high and is composed almost entirely of boulders and cobbles. These cannot have come from the drumlin immediately behind the beach for the sizes there are much smaller. Instead, they must have been carried by storm waves around the northeast point.

About 200 m southwest of the point there is a sudden change in the size of the shingle. The particles become much smaller and sand becomes dominant. This may demark the boundary of the effect of storm waves. Also there is a scarp of old marsh grass (Spartina patens) there and only the largest storm waves can lift cobbles over this resistant scarp.

From there south westward, sand predominates. The development of the spit has dammed up the sediment coming down the South River. This is now deposited in a sand bar. This bar where it extends into the North River, recurves back to Fourth Cliff. At the north west corner, the bar has become anchored by extensive beds of mussels. The top of the bar is practically devoid of vegetation or animal life. But sand waves, current ripple marks and rhomboid ripples and rill marks are common.

Cummulative Milage	Interval Milage	
47.9	4.8	Return to Rt. 3A via the same route in reverse.
49.4	1.5	Turn right on 3A and head North to 123
55.1	5.7	Take a sharp left onto 123 and follow the signs to Rt. 3. Follow Rt. 3 North to Boston.

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