TRIP A-7

THE HILLSBORO PLUTONIC SERIES IN SOUTHEASTERN NEW HAMPSHIRE FIELD CRITERIA IN SUPPORT OF A PARTIAL MELTING PETROGENETIC MODEL

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Introduction

The Hillsboro Plutonic Series consists of a group of plutonic intrusive rocks that crop out in southeastern New Hampshire. The rocks in this series are listed below in their apparent chronological order based on intensity of deformation or foliation and their crosscutting relationships. The locations of the major intrusive bodies of the various rock types are shown in Figure 1.

Magmas of the Hillsboro Plutonic Series were intruded into the metasedimentary rocks of the Merrimack Group. The Merrimack is made up of schists, quartzites, phyllites and calc-silicate granulite rocks of the Kittery, Eliot, and Berwick formations, all of Silurian(?) age (Billings, 1956). The Littleton Formation (Devonian), although not part of the Merrimack Group, is also present to a limited extent in southeastern New Hampshire (Billings, 1956 and Sriramadas, 1966).

The Rockingham anticlinorium is the major structural feature in south-eastern New Hampshire. It lies between the Atlantic Ocean and the Fitchburg pluton (Billings, 1956) and is oriented northeast-southwest.

The chief purpose of this field trip is to demonstrate to the participants some of the field criteria that so strongly imply the granite-to-norite intrusive sequence. The partial melting of deep crustal material is used by the author to provide the mechanism for this intrusive sequence.

During the course of the trip several stops will be made to observe outcrops which exhibit other items of regional stratigraphic and structural interest. The phyllitic Calef member of the Eliot Formation, and the evolution of S_1, S_2, and S_3 planar structural elements are discussed in the road log.

Acknowledgments

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Petrography of the Hillsboro Plutonic Series

The brief descriptions given below were condensed from the detailed petrography of the rocks in the Haverhill 15' quadrangle (Sundeen, 1970).

Sweepstake norite (last of the series to be emplaced) - dark purplish-gray to black, coarse grained, massive norite. It is composed of labradorite, hypersthene and augite.

Island Pond diorite - mottled dark greenish-gray to black, coarse grained, massive diorite. It is composed of biotite, hornblende, actinolite, augite and andesine-labradorite.

Exeter diorite - mottled, dark greenish-gray, coarse grained, generally massive diorite. It is composed of biotite, hornblende,actinolite, oligoclase and quartz.

Sweepstake diorite - mottled light to dark greenish or purplish-gray, medium to coarse grained with both massive and foliated textures. It is composed of biotite, actinolite, andesine-labradorite and quartz.

Quartz monzonite - light gray to light brown, medium grained, massive to moderately foliated. It is composed of quartz, microcline, oligoclase, biotite and muscovite.

Ayer granodiorite - creamy to bluish-gray, coarse grained, slightly foliated quartz monzonite[1] with a porphyritic texture. It is composed of quartz, oligoclase-andesine, microcline, biotite and muscovite with microcline phenocrysts.

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[1] In the Haverhill quadrangle rocks which appear to be an extension of the Ayer Granodiorite series from the Manchester quadrangle differ in composition and dominant texture from the non-porphyritic granodiorite in the type locality in Ayer, Massachusetts (Jahns, 1962, p. 112).

Island Pond porphyritic quartz monzonite - light creamy gray to dark greenish-gray, foliated quartz monzonite, with a porphyritic texture. It is composed of quartz, microcline, oligoclase, and biotite with microcline phenocrysts.

Two-mica granite (first of series to be emplaced) - light gray to light brown, medium to coarse grained, massive to intensely foliated, composed of quartz, microcline, oligoclase, biotite and muscovite with microcline phenocrysts common in the foliated granite.

Petrology and Geochemistry

Questions regarding the "where" and "what" of rocks in the Hillsboro Plutonic Series have been answered by field work and thin section petrography. A two dimensional picture has been developed as a regional geologic map. But before the third dimension (depth) and a fourth dimension (time) can be added, a fuller understanding is necessary of the details of "how" these magmas were generated and the evolution of these magmas prior to emplacement.

It is important to know whether these plutons in southeastern New Hampshire are either rooted in a major batholith a few thousand feet below the surface or represent ends of "straight-pipes" to a former hot spot at the crust-mantle interface. Models for gravity and magnetic data would differ significantly from one petrogenetic model to another.

On this field trip evidence for the sequence of intrusion (granite to norite) will be examined. Figure 1 in the guidebook shows the distribution and relative abundance of the various rock types. In addition to the field data, standard chemical (10) and trace element (12) analyses were determined for selected rock samples.

Major Element Oxides

The results of the analyses plotted on AFM and CaNaK variation diagrams are similar to results of other complex igneous provinces such as the Batholith of Southern California (Nockolds and Allen, 1954). The smooth lines in the variation diagram of the Southern California Batholith are believed to represent a line of evolution of related magmatic liquids. Phases stable under high temperature and pressure conditions consist of relatively higher percentages of Fe, Mg, and Ca than those phases stable under lower energy conditions. Labradorite, hypersthene, and augite would be expected to crystallize first, settle out and leave a residual melt enriched in K, Na, and SiO_2. The residual melt of granitic composition would be one of the last to be emplaced.

Does the similarity of variation diagrams constructed from data from the Hillsboro Plutonic Series and from the Southern California Batholith require that their petrogenesis likewise be similar? Fractional crystallization with successively more silicic residual melts seems to be a reasonable interpretation for the igneous history of the area studied by Nockolds and Allen.

What about southeastern New Hampshire where magmas of granitic composition were intruded before those magmas of a dioritic or noritic composition? It is reasonable to expect that successive magmas generated from the partial melting of crustal rock would have compositions that would plot as a smooth continuous curve on a variation diagram. Those mineral phases which were the last to form from residual magmas during cooling in a fractional crystallization process would be the first to become magmas as temperatures increased during a partial melting process of crustal material. The first melts would be rich in Na, K, and SiO_2 and the desilicified crustal material would become richer in Fe, Mg, and Ca. The composition of the melts produced from desilicified residual crust would become increasingly more mafic as temperatures increased.

Although variation diagrams of plutonic series with differing petrogenetic histories may show remarkably similar curves, the direction in which the line progresses (based on the chronological order of the magmas produced) is reversed.

Trace Elements

Rare earth concentrations were determined for eight elements (La, Ce, Pr, Nd, Sm, Gd, Dy, and Y) for selected samples of the Hillsboro Plutonic Series. Results showed that 1) the total concentration of all rare earths was greatest in granite and quartz monzonite and 2) the relative abundance of the light rare earths (La, Ce, Pr, Nd) to the heavy rare earths (Gd, Dy and Y) was also greatest in granites, quartz monzonites, and quartz diorites. These abundance trends are easily explained (Ringwood, 1955) and are compatible with both fractional crystallization and partial melting models.

Rb, Sr, and K concentrations were determined and Rb/Sr and K/Rb were plotted against (1/3 SiO_2 + K_2O - CaO - MgO - FeO). Wide scatter in these ratios made it impossible to define a constant trend.

Conclusion

Geochemical studies to date exhibit trends which can be explained by both fractional crystallization and partial melting petrogenetic models.

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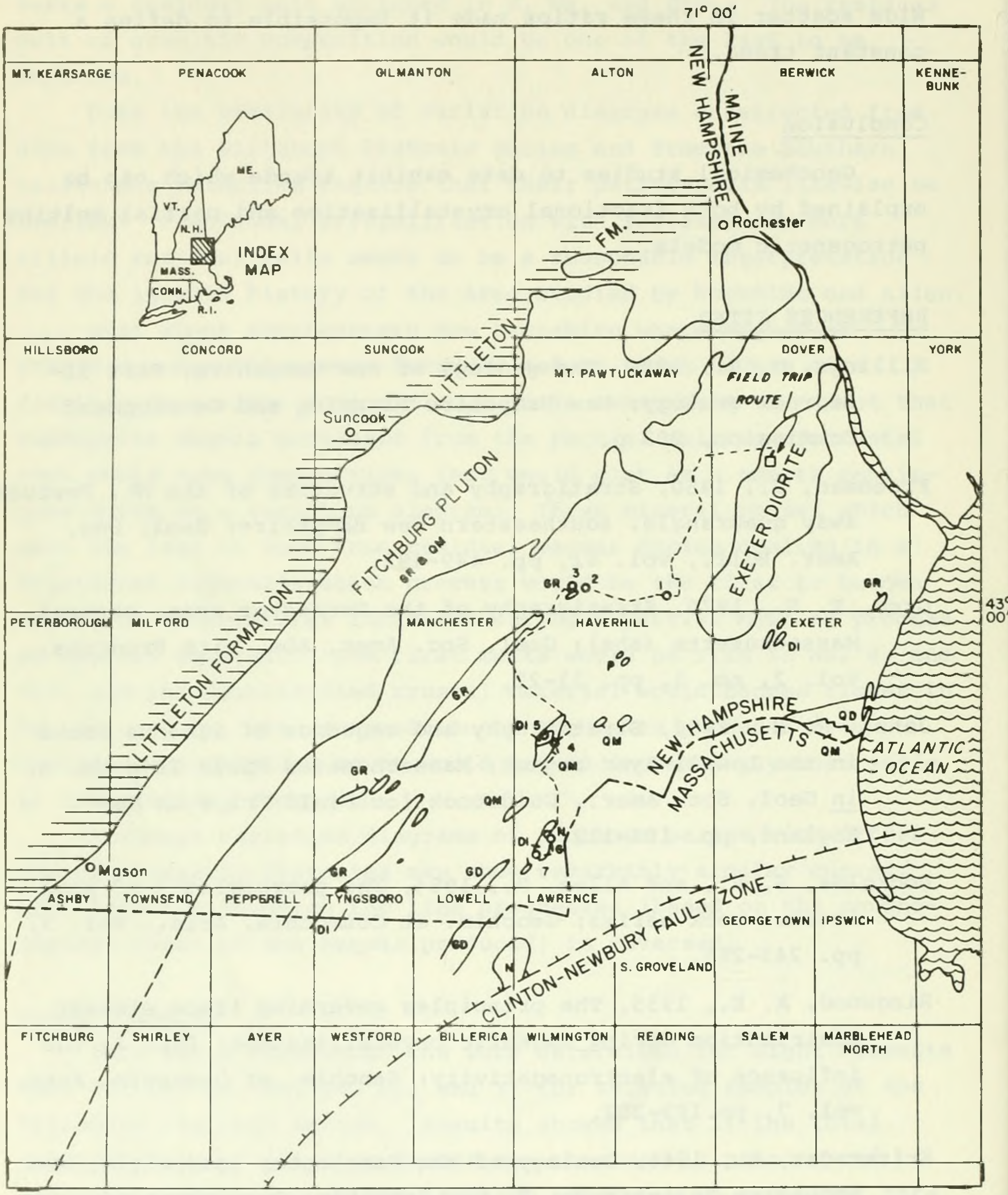

FIGURE 1. LOCATION OF THE MAJOR INTRUSIVE BODIES OF THE VARIOUS ROCK TYPES IN THE HILLSBORO PLUTONIC SERIES, SOUTHEASTERN NEW HAMPSHIRE.

(GR = GRANITE; QM = QUARTZ MONZONITE; GD = GRANODIORITE, QD = QUARTZ DIORITE; DI = DIORITE; N = NORITE; P = PEGMATITE)

ROAD LOG FOR TRIP A-7

Proceed easterly from Concord on Route 4 for 34 miles to the campus of the University of New Hampshire at Durham, where a brief stop is made near the Student Union Building to examine several outcrops of the Exeter Diorite. The path from the parking lot to the old library hall is paved with Exeter Diorite stepping stones. A "heads-down" walk along this path will give a quick demonstration of the variety of colors and textures present locally in the Exeter Diorite. A thin, white aplite dike may be seen in a small outcrop(?) of Exeter Diorite on the College Brook path between the Union and the library. Begin road log.

Mileage

0.0 Turn right (east) upon exiting from the parking lot and proceed to Madbury Road.

0.3 Madbury Road at the U. S. Post Office Building. Turn left (north) onto Madbury Road and proceed to Route 4.

0.65 Junction Route 4. Proceed west on Route 4. The large outcrops are Exeter Diorite. Notice the complex joint system.

4.45 Fresh outcrops at Lee Five Corners (Route 155) are schists of the Eliot Formation.

5.95 Junction Route 125. Proceed south on Route 125.

6.95 Wheelright Pond on left.

7.00 Schists and granulites of Berwick Formation on right.

10.05 Intersection Route 152. Continue south on Route 125. This road is locally known as the Calef Highway and it follows the old railroad bed of the Boston and Maine Railroad.

11.35 Intersection Route 155. Outcrops are composed of a phyllitic member of the Eliot Formation.

13.15 Turn right (west) onto small tarred road (this road leads to Hedding Campground if a left (east) turn were made off of Route 125).

13.40 Bear left at fork in road.

13.55 Outcrops along the road are typical of the Calef member of the Eliot Formation. The Calef is composed of a pyritiferous, carbonaceous phyllite and is a distinctly different facies of the calcareous Eliot Formation. It crops out along the Calef Highway in a band less than a mile wide striking NNE-SSW and has been traced for about eight miles (Freedman, 1950). This same type of phyllitic rock occurs along the eastern flank of the Rockingham anticlinorium.

This occurrence also is less than a mile wide and has been traced along a NNE-SSW trend for about seven miles (Billings, 1956; Sundeen, 1970). Several thoughts about the Calef come to mind, teasing the imagination. Could this phyllite be used as a lithologic-stratigraphic marker within the otherwise monotonously consistent Eliot Formation? And, could the Calef and similar phyllites in southeastern New Hampshire correlate with phyllites in the Worcester Formation (Pennsylvanian) in northeastern-central Massachusetts? A recent paper about this area (Grew, 1970) describes a phyllitic facies in the Oakdale Formation (Silurian) which has been correlated with the Merrimack Group. Grew indicates that in the Worcester area, the phyllite represents a lower metamorphic facies of the Oakdale. In southeastern New Hampshire, the Calef is a different sedimentary facies within the Eliot. And so the battle goes on . . .

14.65 Junction with Main Street of Epping. Turn left (south).

15.20 Bridge over Lamprey River.

15.30 Old Route 101. Turn left (east).

15.55 Junction Route 125. Turn right (south) at traffic lights.

15.85 Boston and Maine Railroad. To the southeast are the clay pits for the Goodrich Brick Company.

16.25 Intersection Route 101. Turn right (west).

16.55 STOP 1 Boston and Maine Railroad. At this stop the characteristics of the Calef member and its occurrence in the Eliot Formation will be studied. This occurrence and one other about one mile to the south extend the Calef member an additional three miles south along strike from the area designated by Freedman (1950). Both schists and phyllites are present in these relatively fresh outcrops on the north side of the road. Notice the crenulations (minor folds) in the phyllite. There are two sets of minor folds of the same size and their fold axes describe a plane parallel to the bedding plane. Other lithologic units present are porphyroblastic (biotite) schists, and quartz-biotite schists. Proceed west on Route 101.

19.05 STOP 2 The large outcrops on the left (south) side of Route 101 are schists and granulites of the Eliot Formation. The purpose of this stop is to observe and discuss the planar structural features of these metamorphic rocks.

Along the outcrop from west to east are examples of compositional bands that probably represent original bedding (S_1). In these beds are mica (biotite) flakes oriented parallel to the bedding plane, a foliation subsequent to deposition caused by metamorphism (S_2). Both S_1 and S_2 have been slightly folded at the western edge of the outcrop. At the eastern edge of the outcrop, the folds have become isoclinal, slip cleavage has occurred parallel to the fold axial planes, and the foliation due to orientation of micaceous minerals is now parallel to the axial plane, not the bedding plane, and is designated S_3. Proceed west on Route 101.

19.65 STOP 3 The rock in the outcrop at this stop is two-mica granite. This granite exhibits schlieren, foliation, and elongated clusters of minerals. These textural features are the result of tectonism synchronous with the emplacement of granitic magma. (If time permits, an additional stop will be made at the next outcrop about 0.2 miles further west on Route 101.)

The dikes intruding the Eliot Formation are rhyolitic(?) and andesitic(?) in composition. They belong to the White Mountain plutonic-volcanic series of Jurassic age (Freedman 1950, Billings, 1956). These dikes are probably associated' with the Little Rattlesnake Hills volcanic complex located about three miles to the southwest and with the Pawtuckaway Mountain ring dike about six miles to the northwest (Freedman, 1950).

20.00 Lamprey River

20.85 Junction with To Routes 102, 107, and 101. Bear left (south) and follow signs to Route 102 and Chester.

22.05 Junction Routes 102 and 107. Bear right (southwest) and follow Route 102.

23.40 Little Rattlesnake Hills on right (west).

24.60 Entering town of Chester. Route 102 is roughly parallel to the contact of the Berwick and Eliot formations.

26.40 Lane Road to right (northwest) leads to another area where the two-mica granite crops out extensively. The granite is cut by a diabase dike about sixty feet wide, striking generally north-south and dipping steeply to the west (Sundeen, 1970). Continue south on Route 102.

28.80 Center of Chester and junction with Route 121. Turn left (east) on Route 121.

28.95 Junction Route 121-A, bear right and continue on Route 121 to Hampstead.

32.05 Television relay tower on Walnut Hill. For the last two miles the schists and granulites seen in outcrops belong to the Eliot Formation. This part of the Haverhill quadrangle is intruded by numerous small granite, quartz monzonite, or pegmatite bodies that generally are concordant with the foliation of the host rock.

35.55 Tel Noar Youth Camp. This area marks the northermost edge of the Island Pond porphyritic quartz monzonite.

36.35 Center of Hampstead. Turn right (west).

37.05 Sharp left turn in road. Private road to Governors Island on right.

37.15 STOP 4 Dirt road on left, pull in and park automobiles. On the west side of the road is a relatively fresh outcrop of the Island Pond porphyritic quartz monzonite. Notice the strongly deformed texture. There is also a distinct banding due to relative amounts of biotite and feldspars. This outcrop is representative of the mineralogy and texture of the Island Pond porphyritic quartz monzonite.

At this point, it would be best to consolidate the group into as few cars as possible. We will backtrack and follow the road to Governors Island.

37.55 STOP 5 A small inlet nearly reaches the left (south) side of the road. On the north side of the road are large boulders and cliffs. These are made up of the Island Pond diorite. Notice the contrast in textural properties, namely, a massive texture. Mapping of the area (Sundeen, 1970) shows the massive diorite is surrounded by the foliated porphyritic quartz monzonite.

The sequence of intrusion of the Island Pond plutonic rocks as suggested by field observation is: 1) porphyritic quartz diorite, synchronous with late stages of tectonism and then 2) massive diorite.

Return to cars parked at STOP 4 and proceed south to join Route 111.

38.70 Junction Route 111. Turn right (west) onto Route 111. Outcrops along the next several miles are schists of the Eliot Formation and quartz monzonite.

39.70 Salem town line.

39.95 Road cuts back to left (southeast). Make this sharp turn to the left. Poorly exposed outcrops of porphyritic quartz monzonite are exposed on the south side of the road and they are close to the southern limit of this plutonic body. Proceed past the Mystery Hill area.

41.30 Main Street. Turn right (south) and continue into Salem Center.

41.65 Fork in road. Continue straight ahead (left fork).

44.30 STOP 6 Pine Grove Cemetery. Park automobiles on the old side road at the southern entrance to the cemetery. This will be a short stop to gain a quick glimpse of the variety of rock types present in the Sweepstake diorite pluton. The cemetery is underlain by diorite and norite. The stone wall was built of stone quarried locally and (as did the sidewalk near the Student Union) it displays an interesting variety of rock colors, textures and eccentricities. In general the more deformed textures are indicative of quartz diorites, the more massive textures are indicative of diorite and norite. Proceed south and immediately join Route 97.

44.35 Route 97. Turn right.

44.65 Cross School Street. Continue southwest on Main Street.

44.75 Turn left (south) onto next street.

45.45 Turn right (west) onto Veterans Memorial Parkway.

45.65 STOP 7 Intersection of Veterans Memorial Parkway and Geremonty Drive. This outcrop exhibits a variety of igneous intrusive phenomena. A full description is in the literature (Sundeen, 1970). A list of items of interest is given below in the probable geologic order of occurrence:

Slightly foliated quartz diorite (biotite-chlorite mafics)
Biotite schist-xenoliths from the Eliot formation
Massive diorite (actinolite-diopside mafics)
Amphibole-rich contact zone between early and late diorites
Zoned pegmatite dikes displaying graphic textures and garnet-tourmaline-apatite aplitic cores
Gossan; remnant of a joint-oriented sulfide vein.

The preservation of schistose xenoliths and the foliation of the quartz diorite (parallel to the regional foliation in the metasedimentary rock) sets limits on the age of intrusion of the Sweepstake quartz diorite. It can be no older than regional metamorphism (Late Devonian) and can be no younger than the end of the Acadian Orogeny (Late Devonian; possibly a last pulse in very Early Mississippian). The diorites and norites are younger than the quartz diorite (a conclusion based on their having massive textures), and therefore were intruded after the last tectonic pulse.

Veterans Memorial Parkway continues west passing south of Rockingham Park. This race track has the unique distinction of being the only one in the country that regularly runs sweepstakes to supplement state funds for public education. Just west of the park is the entry ramp to Interstate 93.

End of Trip.