United States
Department of the Interior
Geological Survey

BEDROCK GEOLOGY OF THE PLAINFIELD-DANIELSON AREA, CONNECTICUT

By

HELEN ROBERTA DIXON

Open File Report 1968

"....The history of the Taconics and of the southern Appalachian belt will have to be worked out gradually and each area that is studied will have to be regarded in the light of its relation to the whole province. For no explanation of the structure in one area, however alluring in its simplicity, can stand fast unless it fits in with all the facts that have been established in other adjoining areas."

(Knopf, E. B., 1935).

Table of contents (continued)

Table of contents (continued)

Illustrations

Illustrations (continued)

Illustrations (continued)

Illustrations (continued)

Plates (continued)

Tables

Tables (continued)

Abstract

The Plainfield-Danielson area includes the Danielson, Hampton, Plainfield and Scotland quadrangles near the northeastern corner of Connecticut. It is part of the eastern highlands of Connecticut, and is underlain by medium- to high-grade metamorphic Paleozoic rocks. The area is predominately rural and wooded. The hilly topography is largely controlled by the attitude and erodibility of the underlying bedrock, but a thin blanket of glacial till covers most of the bedrock.

Most of the central portion of eastern Connecticut is within the southern extension of the Merrimack synclinorium of New Hampshire. The synclinorium in Connecticut is bordered on the west by the folds of the Bronson Hill anticlinorium, and on the south and east is cut off by a major thrust fault, the Honey Hill-Lake Chargoggagoggmanchauggagogg-chaubunagungamaugg fault (known as the Lake Char fault). The internal structure within the synclinorium in Connecticut is interpreted to be a large, recumbent syncline overturned from west to east. The recumbent syncline has been mapped in three segments and is designated the Hunts Brook-Chester-Hampton syncline. The Plainfield-Danielson area is situated between the Lake Char thrust fault on the east edge of the synclinorium and the axial surface of the recumbent Hampton syncline in the core of the synclinorium. The rocks of the area are, therefore, primarily those in the upper plate of the thrust fault and the normal limb of the recumbent syncline. The rocks of the lower plate are exposed in a small area along the eastern edge of the area, and those in the overturned limb of the syncline are exposed in the northwestern corner of the area.

The bedrock units of the Plainfield-Danielson area include various metasedimentary and metavolcanic rocks of lower to middle Paleozoic age,

and plutonic gneisses of probable igneous origin. The oldest rocks are those of the Plainfield Formation of Cambrian(?) age in the lower plate of the Lake Char fault. In the Plainfield-Danielson area the Plainfield Formation is primarily quartzite with lesser amounts of mica-quartz schist and hornblende gneiss. It occurs as lenses interleaved with thicker layers of the Sterling Plutonic Group.

The oldest unit in the upper plate of the Lake Char fault is the Quinebaug Formation of probable Middle Ordovician age. The unit consists of a lower and an upper member of layered hornblende gneiss, biotite gneiss and amphibolite, and a middle member, the Black Hill Member, of calcareous mica schist. The rocks were apparently well-layered, mixed volcanic tuffs and sediments and subsidiary nonvolcanic sediments, although the Black Hill Member was probably mostly reworked volcanic material. The unit has an approximate apparent thickness of about 7,000 feet, but it thins to the north as it is cut out at the base along the Lake Char fault. The rocks were regionally metamorphosed to the sillimanite grade. The unit is strongly folded, faulted and cataclastically deformed. All the rocks of the lower member and many of the Black Hill and upper members are mortar gneiss, mylonite gneiss, mylonite and blastomylonite.

The Tatnic Hill Formation overlies the Quinebaug Formation in apparent conformity. It consists of a sequence of metasedimentary rocks of probable Middle Ordovician age. The formation has been subdivided into a lower member consisting of various micaceous gneisses, commonly with garnet and sillimanite, the Fly Pond Member of calc-silicate gneiss in the middle, and the Yantic Member of micaceous schist at the top. The unit has a maximum apparent thickness of about 6,000 feet. It thins toward the north, and the thinning is reflected in all subunits of the formation except the Yantic Member at the top. The grade of metamorphism of the formation varies from sillimanite-potassium feldspar at the base to staurolite-kyanite at the top of the Yantic Member; most of the unit is in the lower sillimanite grade. The rocks are well folded, and those in the lower part of the lower member, especially, are strongly faulted and commonly cataclastically deformed.

The Hebron Formation overlies the Tatnic Hill Formation in apparent conformity. It consists primarily of thinly layered calcite-biotite schist, biotite schist and calc-silicate rock. The Hebron Formation in the overturned limb of the Hampton differs from the Hebron in the normal limb in that it is less well layered and contains a higher proportion of biotite schist and less abundant calc-silicate rock. The Hebron was apparently originally deposited as a series of calcareous siltstones of Middle Ordovician to Silurian age. The unit has an approximate thickness of 500 to 1,000 feet. The rocks are mostly in the staurolite-kyanite grade of metamorphism, but locally are in sillimanite grade. The rocks are well folded but only locally are they faulted and cataclastically deformed.

The Hebron Formation is overlain by the Scotland Schist. The contact is apparently conformable and is gradational across a few feet. The lower part of the Scotland Schist consists of interlayered biotite granular schist and coarse muscovite schist, and local exposures of graded bedding indicate that the Scotland Schist is on top of and younger than the Hebron Formation; locally a thin quartzite occurs at the base. Above the basal zone the unit consists of massive muscovite schist commonly with staurolite and garnet, and less commonly kyanite. Within the Plainfield-Danielson area the unit has a maximum thickness of about 800 feet, but the top is not exposed. The unit is primarily in the staurolite-kyanite grade of metamorphism, but along the western edge of the area is in sillimanite grade.

The Canterbury and Eastford Gneisses form two large sills primarily within the Hebron Formation. The Canterbury Gneiss occurs in the normal limb of the recumbent Hampton syncline and consists primarily of biotite granodiorite gneiss with common accessory epidote and allanite. The Eastford Gneiss is in the overturned limb of the syncline and consists primarily of biotite quartz monzonite gneiss, without accessory epidote and with less abundant biotite than the Canterbury. Both sills are either pre- or syntectonic. Two foliation planes, as defined by the orientation and alignment of biotite flakes are commonly developed in the Eastford Gneiss and less commonly in the Canterbury Gneiss. A strong lineation is formed in both by streaks of biotite at the intersection of the two foliation planes.

The gneisses of the Sterling Plutonic Group form sills interleaved with the Plainfield Formation in the lower plate of the Lake Char fault. The Sterling in the Plainfield-Danielson area has been subdivided into the Hope Valley Alaskite Gneiss and the Scituate Granite Gneiss primarily on the basis of exposures in the adjoining areas, as the rocks within the area are of limited exposure and are almost all cataclastically deformed. The Hope Valley Alaskite is a quartz-microcline-plagioclase gneiss with minor muscovite and biotite and typically containing aligned quartz rods. The Scituate Granite Gneiss of this area differs only in that it contains slightly more biotite. The rocks adjacent to the Lake Char fault are mylonite, mylonite gneiss and blastomylonite, and in the rest of the area they are primarily mortar gneisses. The Sterling gneiss is probably pretectonic, but the age is not well established.

Dikes and sills of pegmatite occur in all the major bedrock units of the area. The largest pegmatites and the greatest concentration of them occur in the Fly Pond and the Yantic Members of the Tatnic Hill Formation. These are close to the Canterbury Gneiss and may have formed as residual liquids from the Canterbury. Other pegmatites in the area, however, probably are not related to the Canterbury, and some may have formed at different times. The majority of the pegmatites are foliated and the foliation is parallel to the regional foliation of the host rock. A few small pegmatites are unfoliated. A small sill of unfoliated gabbro is exposed in the Plainfield quadrangle. The gabbro is probably satallitic to the Preston Gabbro south of the Plainfield-Danielson area.

Rocks in the Plainfield-Danielson area were regionally metamorphosed to staurolite-kyanite, sillimanite and sillimanite-potassium feldspar grades of metamorphism. Subsequent to regional metamorphism the rocks were cataclastically deformed and converted to mortar gneiss, mylonite gneiss, mylonite and blastomylonite. The appearance and fabric of the cataclastic rocks vary considerably depending on the composition of the original rock, the degree of granulation, and the degree of recrystallization and of neomineralization. The mortar gneisses and mylonite gneisses contain small to coarse grains of the resistant minerals, primarily feldspars, hornblende and locally garnet, in a very-fine-grained matrix of quartz, biotite and feldspar. The mylonites are rather uniformly very-fine-grained rocks in which all minerals have been granulated. In many of the mylonite gneisses and mylonites quartz, biotite, some hornblende, and to some extent plagioclase recrystallized during cataclasis. The blastomylonites were more or less thoroughly neomineralized during cataclasis with the formation of chlorite, epidote and sphene from hornblende and biotite, and sericite, epidote and calcite from plagioclase.

The Lake Char thrust fault, across the eastern edge of the Plainfield-Danielson area traces south to the Preston Gabbro where it is continuous with the Honey Hill fault. The fault forms the contact between the Quinebaug Formation in the upper plate and the Plainfield Formation and Sterling Plutonic Group in the lower plate. The fault trace parallels the structural trend of the units above and below the fault plane and no actual displacement can be proved along the fault within the Plainfield-Danielson area, although the indications are that the Quinebaug Formation is progressively cut out northward by the fault. The fault is mapped primarily by the cataclasis of the rocks in a wide zone above the fault and a narrower zone below it. The cataclasis increases in intensity toward the fault contact. The amount of stratigraphic displacement between the Quinebaug Formation and the Plainfield Formation cannot be determined. A well developed lineation in many of the cataclastic rocks adjacent to the fault indicates the movement direction was toward the southeast.

A number of smaller thrust faults occur primarily in the upper plate of and are subparallel to the Lake Char fault. The rocks adjacent to these faults are also strongly cataclastically deformed although the zone of cataclasis is not as wide as that adjacent to the Lake Char fault. The smaller thrust faults are most commonly observed in the lower member of the Tatnic Hill Formation, but they are probably equally common in the Quinebaug Formation.

A system of northwest-trending high-angle faults offset the rocks in the upper plate of the Lake Char fault. These probably originate in the zone of the major thrust plane, but indications are that some, at least, offset the Lake Char fault slightly. Most of the northwest-trending faults have offsets of one or two thousand feet, but a few have offsets of more than a mile. Less common are north-northeast-trending high-angle faults. These are subparallel to the structural trend of the bedrock units of the area and are more difficult to map. Both sets of high-angle faults offset the thrust faults. Features which indicate late faulting are common in the rocks of the lower member of the Tatnic Hill Formation and the Quinebaug Formation. These include slickensided foliation surfaces, abundant small faults observed in outcrop which offset both cataclastic and noncataclastic rocks, ultramylonite dikes cutting the cataclastic rocks, breccias in which the clasts are mylonite and quartz veins.

The recumbent Hampton syncline is the major fold of the area and is continuous with the Chester-Hunts Brook syncline southwest of this area. The axial surface of the Hampton syncline goes through the northwestern part of the area primarily in the Scotland Schist and locally in the Hebron Formation. The bedrock units south and east of the axial surface are in the normal limb and those north and west of the surface are in the overturned limb. The emplacement of the Hampton syncline into its present position must have involved two stages of folding. During the first stage the major folds of the area, including the Hampton syncline, were formed. In the second stage the early folds were refolded around a north trending axis, and were overturned from west to east. A third, and later stage of folding probably accompanied formation of the Willimantic dome west of the Plainfield-Danielson area, and resulted in an open syncline in the normal limb of the Hampton syncline across the western half of the area.

Successive stages of deformation can be demonstrated to some extent in the small scale structures of the area. The dominant regional foliation strikes northeast and dips northwest and is subparallel to the present attitude of the axial surface of the Hampton syncline as well as to the general attitude of the thrust faults. The regional lineation plunges gently north and is parallel to the axial plunge of the Hampton syncline. Both the regional foliation and lineation probably formed during the second stage of folding, or the overturning from west to east, of the Hampton syncline. Many small scale folds which have a gentle north plunge also probably reflect this stage of folding. The earlier stage of folding is reflected by other foliation directions, mineral lineations which are folded by the later folds, and small scale folds with varying plunge directions. The general direction of movement on the thrust faults and of the overturning of the Hampton syncline is the same, and the thrust surface is about parallel to the axial surface of the syncline; it seems likely, therefore, that the general west to east movement of the two structures took place at about the same time.

The major economic use of the rocks and minerals of the Plainfield-Danielson area in the past has been for various construction purposes, such as crushed rock for roads, and supports for bridges, dams and buildings. There are no indications in the rocks of mineral concentrations of economic significance, and it is probable that the major use of the rocks in the future will continue to be in the construction industry.

INTRODUCTION

The Plainfield-Danielson area includes the Danielson, Hampton, Plainfield and Scotland 7 1/2" quadrangles, and covers approximately 210 square miles within the eastern highlands of Connecticut (see fig. 1). The four quadrangles are near the northeastern corner of the state, and include all of the townships of Scotland, Hampton, Brooklyn and Canterbury, and most of Plainfield and Pomfret. The area is underlain by medium- to high-grade metasedimentary and metavolcanic rocks and granitic gneisses of probable lower Paleozoic age, that are truncated by a major thrust fault along the eastern side of the area. Above the fault the rocks were folded into a major recumbent syncline, the axial surface of which goes through the northwestern part of the area. The major portion of the rocks in the report area are, thus, in the normal limb of the recumbent syncline and in the upper plate of the thrust fault.

The northeastern part of Connecticut is predominately a rural area. It is now about 80 percent forest covered, although at one time about the same amount was cleared farm land. As small industries came into the area, mostly mills along the rivers, the farm land was gradually abandoned and allowed to go back to timber, and today about the only remaining evidence of the earlier land development is the maze of stone walls that criss-cross the country side. The main industries of the area are small scale farming and small industrial plants in some of the villages. The largest community within the report area is Danielson with a population of about 6,000; other villages include Plainfield, Moosup, Wauregan, Dayville, and Rogers. Large communities serving the area are Norwich to the south, Willimantic to the west and Putnam to the north.

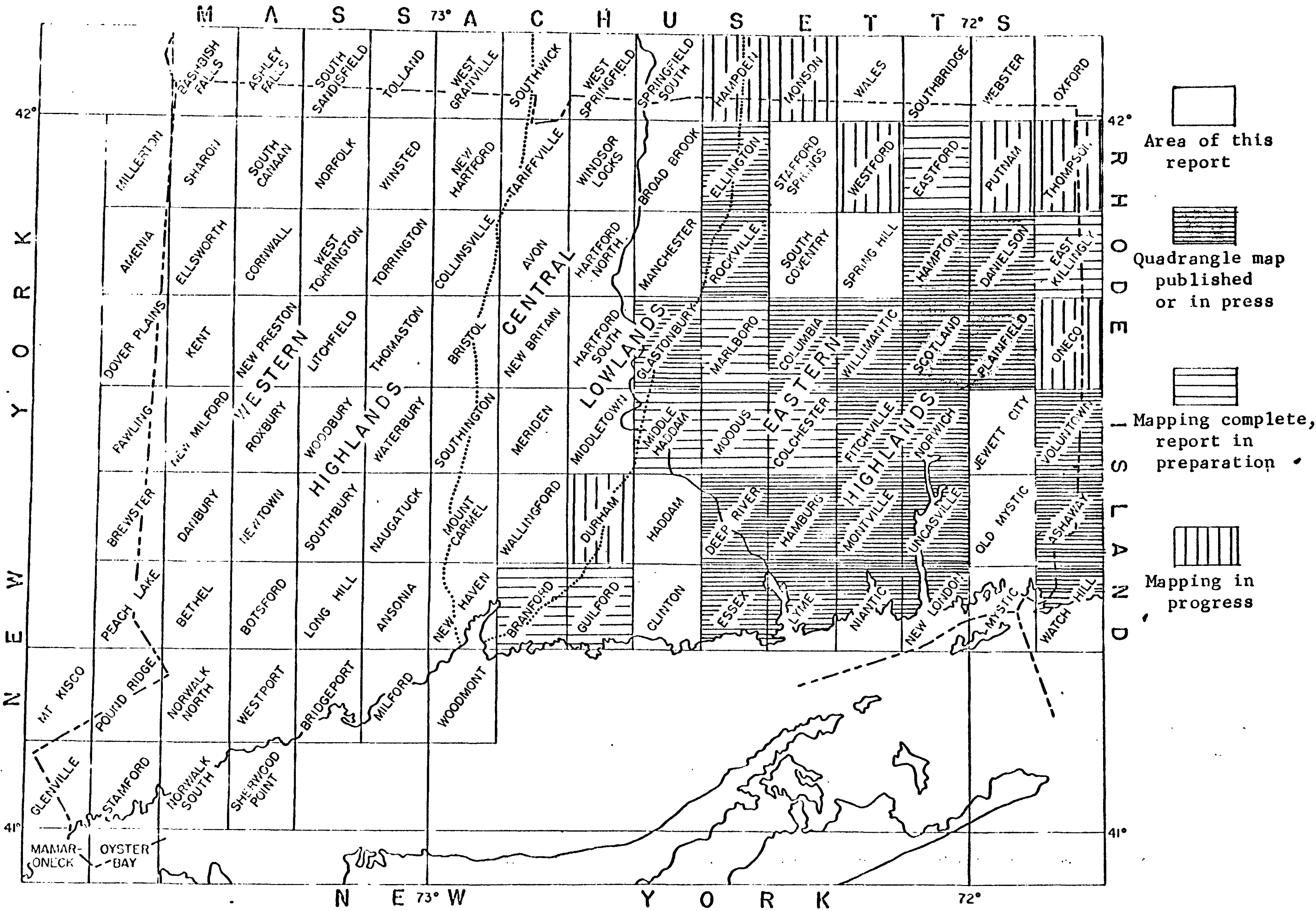


Figure 1.--Index map of Connecticut, showing status of bedrock mapping in the eastern highlands as of January, 1968

An excellent system of hard surface roads throughout the area provides easy access to all parts. There are very few points within the four quadrangles which are as much as a mile from a good road. Major highways include U. S. Rt. 6, across the southern part of the Hampton and Danielson quadrangles, and U. S. Rt. 44, in the northern part of the Hampton quadrangle. The Connecticut turnpike and the new extension of the turnpike north to Massachusetts go through the eastern edge of the Plainfield and Danielson quadrangles. A branch of the New York, New Haven and Hartford Railroad from Norwich to Putnam, goes through the eastern part of the area, and a second branch, from Norwich to Willimantic goes through the southwest corner, along the Shetucket River. A third branch, from Willimantic to Putnam, went across the Hampton and the northwest corner of the Danielson quadrangles, but was recently abandoned and the tracks removed.

The Quinebaug River is the largest drainage system within the map area. It drains all of the Plainfield and Danielson quadrangles, and has a flood plain as much as a mile wide through the central parts of the two quadrangles. Other rivers include the Shetucket River in the southwestern corner of the Scotland quadrangle, the Natchaug River in the western part of the Hampton quadrangle and Little River, draining the central parts of the Hampton and Scotland quadrangles. The rivers are all shallow, and bottom on bedrock in several places.

Topography of the area is gentle, and local relief is commonly about 200 to 300 feet. The lowest elevation is 100 feet along the Quinebaug River in the southern part of the Plainfield quadrangle and along the Shetucket River. The highest point is 810 feet on Sunset Hill in the central part of the Hampton quadrangle. Although a mantle of glacial till covers the bedrock of the area, the till is not thick enough in most places to mask the strong bedrock control of the topography. Details of the topography in the uplands are most commonly parallel or subparallel to the strike of the layering or foliation in the bedrock. Many small valleys of the area follow either the trend of the easily eroded rock units, or follow faults and fractures in the bedrock. A similar bedrock control cannot be demonstrated, however, for the larger rivers of the area.

Bedrock exposures are irregularly distributed throughout the map area. Two fairly large areas where exposures are few and scattered are the flood plain of the Quinebaug River and the central part of the Hampton quadrangle, where most of the underlying bedrock is flat lying, easily eroded calc-silicate schist. The calc-silicate rocks of the Hebron Formation and the Tatnic Hill Formation are the most susceptible to erosion of any of the rock types in the area. Several streams, such as Little River and Kitt Brook, follow the trend of units of calc-silicate rock for several miles. In many places exposures of the calc-silicate rock are present only because they have been intruded by pegmatite. The pegmatites are about the most resistant rocks in the area, but few are large enough to influence the topography. The hornblende and biotite gneiss and amphibolite in the Quinebaug Formation are only slightly more resistant than the calc-silicate rocks. They are well preserved only along the western edge of the unit, where they occur on east facing hill slopes capped by the more resistant mica schists of the Tatnic Hill Formation, and along the eastern edge where they are strongly cataclased. The sillimantic mica schists and gneisses of the Tatnic Hill Formation and the granodiorite gneiss of the Canterbury and Eastford Gneisses are fairly resistant to erosion, and commonly form uplands separated by valleys cut into calc-cilicate rock. The muscovite rich schists of the Scotland Schist are the most resistant of the major rock units in the area, and commonly form high bluffs above the Hebron valleys.

The relative erodibility of the rocks of this area is in rather marked contrast to that in the area several miles to the southwest. Lundgren (1964, p. 31-33; 1966a, p. 39) reports that in the Essex and

Hamburg quadrangles the most easily eroded rocks are the sillimantic mica schists of the Brimfield Schist and Tatnic Hill Formation, while the most resistant are the biotite-quartz-feldspar gneisses of the Monson Formation (compositionally similar to the rocks of the Quinebaug Formation) and calc-silicate gneisses. The reason for this difference in erodibility of similar rock types is not understood.

Previous work

Since the early 1800's eastern Connecticut has been mapped by several reconnaissance studies. The earliest account of the area was the "Sketch of the Geology and Mineralogy of New London and Windham Counties" by W. W. Mather (1834). The report included a colored map on which Mather distinguished nine lithologic units, all with a roughly north-south trend, and cross sections. This report is now primarily of historical interest as it generally locates many old and long abandoned quarries, bog iron deposits and peat bogs. It is also one of the earliest attempts to portray geologic relationships of an area by structure sections.

In 1835 the state of Connecticut contracted with J. C. Percival, as geologist, and C. U. Shepard, as mineralogist, to make a study of the geology and mineralogy of the state and to assess its mineral potential. Shepard's work "A Report on the Geological Survey of Connecticut" (1837) is a listing of the various useful minerals occurring in the state, including building materials. Very little mention is made of the Plainfield-Danielson area in the report. Percival spent two summers making east-west traverses across the state, and four more summers engaged in more detailed studies. He was finally forced by the state to cease his field investigations and prepare a report. In 1842 his "Report on the Geology of the State of Connecticut" was written and published. Although Percival

State of Connecticut" was written and published. Although Percival considered the report to be only a "hasty outline" it dutifully records many of his observations in confusing detail. Both the report and the accompanying map are difficult to read, but both are more accurate in detail, at least in eastern Connecticut, than many subsequent reports. A number of his ideas on the distribution and relationships of the various rock units, which were forgotten or ignored in later studies, have been revived by recent detailed work. One of these is the correlation of the Brimfield Schist and the Tatnic Hill Formation, and the suggestion of an overturned fold structure across the central part of eastern Connecticut between the two units. In summing up his description of Unit F (Putnam Group) Percival states, "This range presents several analogies to the formation (D) [Brimfield Schist] in the character and arrangement of its rocks, and the two might indeed be considered as forming a whole, enclosing the range (E) [Hebron Formation] on the East and West; the coarser grained rocks, partly with bucholzite, extending in a narrow band along the borders of the S. West extremity of the latter, apparently forming a connecting link between them....The resemblance of these [parts F and D] is so obvious that it can hardly escape the attention of the casual observer" (Percival, 1842, p. 289).

Between 1898 and 1902 H. E. Gregory directed a reconnaisance study of eastern Connecticut carried out by Gregory, W. E. Ford, Jr., J. H. Perry and C. H. Warren. This work, combined with more detailed work in specific areas by G. F. Loughlin, H. H. Robinson and L. G. Westgate, was incorporated into the "Manual of the Geology of Connecticut" by Rice and Gregory (1906) and the "Preliminary Geologic Map of Connecticut" by Gregory and Robinson (1907). The Manual is a generalized account of the geology of the state intended to reach a wide variety of users (see Rice and Gregory, 1906, Preface). By now the principal value of the report is that it is the source of most of the geologic names used in Connecticut, although the names are poorly defined and, though typical outcrops are given for some units, type localities are not cited. In 1949 "The Geology of Eastern Connecticut" by Foye was published, also as a popular account. Foye's field work was primarily in the central and southern parts of the area, and he relied on the earlier field work for the northern and eastern parts. Both the maps of Gregory and Robinson (1907) and Foye (1949) are essentially similar to Percival's (1842) map, and differ only in detail. A general resume of the rock units in Connecticut was also given by Barrell and Loughlin (1910) and of the granitic rocks of the state by Dale and Gregory (1911).

Specific areas in eastern Connecticut were mapped in more detail than the reconnaisance studies mentioned above. Of particular interest to the area of this report are the studies of the Preston Gabbro and surrounding rocks by Loughlin (1912) and by Sclar (1958). Martin (1925) continued the work of Loughlin from the gabbro south to Long Island Sound.

The most recent compilation of Connecticut geology was "The Preliminary Geologic map of Connecticut" by Rodgers and others (1956) followed by an explanatory text by Rodgers and others (1959). Although no new field work was carried out in eastern Connecticut for the map, it incorporated work done during the 1940's and 1950's by Aitken (1951, 1955), Collins (1954), Herz (1955), Lundgren (1963, 1964), Mikami and Digman (1957), Perhac (1958) and Sclar (1958). This map and text were the prelude to the recent detailed work in Connecticut, and the problems outlined in the text provided much of the justification for the present cooperative program between the Connecticut State Geological and Natural History Survey and the U. S. Geological Survey. Work on the current program began in 1955 and mapping has been carried out by both organizations on 7 1/2" quadrangle maps at a scale of 1:24,000. Quadrangle maps and reports in eastern Connecticut which have resulted from the program include Lundgren (1963, 1964, 1966a and 1967) published by the state of Connecticut, and Feininger (1965 a and b), Goldsmith (1967 a, b, c, and d), Moore (1967), Snyder (1961, 1964 a and b, 1967) and Dixon (plates 2-5) published by the Geological Survey.

The primary purposes of the current bedrock mapping program are to delineate and define the bedrock units of the state, to determine the stratigraphic and structural relationships of the various units and to evaluate the economic potential of the rocks and mineral resources of the state. Under the cooperative program most of the area of the crystalline rocks of eastern Connecticut has been mapped, and it is primarily the quadrangles along the northern and eastern edge that remain to be mapped, though field work is in progress in some of these (fig. 1).

Present work and acknowledgements

Bedrock mapping in the Plainfield-Danielson area was carried out between 1957 and 1965. Mapping was started in the Scotland quadrangle and proceeded through Hampton, Plainfield and Danielson. Mapping and compilation were on topographic base maps at 1:20,000 for publication at 1:24,000. During the course of the work I was assisted by Rachel Barker, Frances Gilbert, Ann Hetzel, Betsy Levin, Grace Nolan, Mary Tisue, and Barbara Voorhies, and for short periods of time by Shirley McDowell, Anita Mook, and Dorothy Rainsford. In the summer of 1957 G. J. Neuerberg, of the U. S. Geological Survey, spent four weeks mapping in the Plainfield quadrangle, and his field notes, maps, and samples were available to me.

The surficial geology of the Hampton quadrangle was mapped by Fred Pessl, Jr., of the Geologic Division of the U. S. Geological Survey, and combined with the bedrock mapping for publication (plate 3). The surficial geology of the rest of the area was mapped by members of the Water Resources Division of the U. S. Geological Survey as part of a water resources inventory of Connecticut. The eastern half of the area is included in the "Water Resources Inventory of Connecticut, Part I. Quinebaug River Basin" (Randall et al, 1966, Thomas et al, 1966), and the western half will be included in a similar report on the Shetucket River basin which is currently in preparation. In addition the surficial geology of the Scotland quadrangle by C. E. Shaw, Jr., was combined with the bedrock geology for publication (plate 5), the work in the Danielson quadrangle by A. D. Randall is in press as a surficial geologic quadrangle map, and Randall's work in the Plainfield quadrangle is planned for future release as a surficial geologic quadrangle map.

I am indebted to numerous associates and coworkers for continuing advice, criticism and assistance during the course of the work, both in the field and in the office. Many field trips and discussions with people working in surrounding areas enabled me to gain a better understanding of the geology of eastern Connecticut as a whole as well as of the Plainfield-Danielson area. Among those actively working in the area whose assistance was most valuable are Dr. L. W. Lundgren, Jr., of the University of Rochester and the Connecticut State Geological and Natural History Survey, and G. P. Eaton, T. G. Feininger, Richard Goldsmith, M. H. Pease, Jr., G. E. Moore, Jr., and G. L. Snyder of the U. S. Geological Survey. I was visited in the field and received many useful suggestions from Prof. M. P. Billings and Prof. J. B. Thompson, Jr., of Harvard University, Dr. J. W. Peoples, Director of the Connecticut State Geological and Natural History Survey, Prof. John Rodgers, Yale University, Rev. J. W. Skehan, S. J., of Boston College, and Dr. L. R. Page of the U. S. Geological Survey. Prof. Billings, Prof. Thompson and Dr. Page critically reviewed and substantially improved the manuscript. Mr. A. D. Randall, of the Water Resources Division, provided valuable information on the location of many isolated bedrock exposures. Mr. R. W. Bromery and Mr. D. R. Mabey advised me on the interpretation of the aeromagnetic maps. I am grateful for the friendly cooperation of the residents of the Plainfield-Danielson area who, almost without exception, allowed me free access to their property.

Definitions and laboratory procedures

Nomenclature of metamorphic rocks and textures is in a particularly confused state. There are almost as many definitions of "gneiss" and "foliation" as there are geology textbooks, and very few are the same. Almost every rock in eastern Connecticut has been called a gneiss by one or another of the previous workers, and by one or another definition of gneiss, almost every rock could fit the term, while by other definitions there would not be a gneiss in Connecticut. For this reason the terminology used in this report is defined here.

The term "foliation" is used in a general sense to designate any parallel fabric element of the rock. The foliation plane is commonly, but not necessarily, a plane of easy cleavage. In most rocks the foliation consists of either or both a schistosity and a compositional banding. Schistosity is defined as a parallel orientation of platy (primarily micas) or tabular (amphiboles and in some rocks feldspars) minerals. By this definition a gneiss which contains only a few per cent of scattered, but oriented micas may possess a schistosity, as well as a schist which contains abundant micas. In most of the metasedimentary and metavolcanic rocks the schistosity is parallel to the compositional banding, and in many of the rocks the compositional banding is probably parallel to the original bedding. In some rocks, however, the plane of compositional banding can be demonstrated to be a plane of shearing. The term bedding is used, therefore, both in the text and on the geologic maps (plates 2-5) only where layering can be demonstrated to be primary bedding on the basis of preserved sedimentary features. In most other rocks bedding is assumed to be parallel to the banding.

The term "schist" is used here as a foliated rock in which the platy or tabular minerals are abundant enough and so oriented that the rock commonly breaks in rough slabs parallel to this orientation. This is a fairly standard definition of a schist, and is essentially the one given in the AGI Glossary (1957). In most schists the platy minerals are coarser (in diameter of flakes) than the granular minerals of the rock. The term "granular schist" is used to designate those schists in which the platy minerals are of the same order of size as the granular minerals. The term "gneiss" is used for a foliated rock in which the platy and tabular minerals are not so abundant as to control the breaking of the rock, and it breaks more across the foliation planes than along them. Many of the gneisses, especially in the metasedimentary and metavolcanic rocks are compositionally banded, but others are not. The term "granulite" is used here for only a few, rare quartz-feldspar-epidote rocks which contain no oriented minerals.

For most rocks the names gneiss and schist are modified by the three or four essential constituents of the rock listed in order of increasing abundance. Thus in a biotite-quartz-plagioclase gneiss, plagioclase is the most abundant mineral, and biotite the least abundant of the three. Other minerals which commonly occur in the rocks of a given unit will be mentioned separately. For a general reference to a lithologic unit, however, a characteristic, but not necessarily abundant, mineral may be used, as in the sillimanite gneiss unit in the Tatnic Hill Formation. In describing a specific rock or sample the same system is used except that all essential minerals of the rock are listed. This is done primarily in the descriptions of the samples for which modal analyses are given. The first part of the description of these samples gives the megascopic appearance, and the second part gives details observed in thin section. In the megascopic description all minerals which are visible with a hand lens are listed in increasing order of abundance. If a rock contains a fairly high percentage of very-fine-grained quartz which is not apparent in hand sample, quartz is unlisted, or indicated as a minor mineral. The mineral order for a given rock may not, therefore, necessarily agree with the order of abundance shown in the modal analysis. This discrepancy is retained because the descriptions are given primarily as an aid in field identification, and the situation commonly arises, especially in the cataclastic rocks.

Nomenclature for the cataclastic rocks is even more confused than is that for regional metamorphic rocks. A number of terms have been proposed and used, but few have been consistently used. Reviews and definitions of the terminology for cataclastic rocks are given by Quensel (1916), Knopf (1931), Waters and Campbell (1935) and Christie (1960).

The one basic distinction which is commonly made in cataclastic rocks is between granulation only, with little or no recrystallization, and granulation with accompanying recrystallization. Thus Bryant and Reed (in press) use the terms mylonite (rare porphyroclasts) and mylonite gneiss (10-90 per cent porphyroclasts) for unrecrystallized cataclastic rocks and blastomylonite (where recrystallized material is largely quartz and feldspar) and phyllonite (where recrystallized material is largely sericite) for recrystallized cataclastic rocks. Knopf (1931, p. 5), however, distinguished between recrystallization "where certain constituents such as calcite and quartz have newly crystallized without change of chemical constitution" and what she terms neomineralization or "transformation of the old mineral constituents into minerals of new and different composition" as "formation of chlorite, albite, hornblende, and epidote in a rock that originally contained pyroxene and a calcic plagioclase". Lapworth (1885) may have had a similar distinction in mind in his original definition of mylonite as he refers to "shattered fragments of the original crystals of the rock set in a cement of secondary quartz, the lamination being defined by minute inosculating lines (fluxion lines) of kaolin or chloritic material and secondary crystals of mica" (Lapworth 1885, p. 559). Blastomylonite was originally defined by Sander (1912, p. 250) as a cataclastic rock in which neomineralization is extensive enough that the cataclastic fabric is difficult to recognize. Recrystallization (in the sense of Knopf, 1931) of quartz and biotite is apparent in most cataclastic rocks of the Plainfield-Danielson area; quartz is commonly fine grained and strongly sutured, and biotite forms a very-fine-grained network either in streaks with granulated quartz and feldspar, or in the rock as a whole. Recrystallization of quartz and biotite does not, however, mask the cataclastic fabric of the rock. Likewise recrystallization of quartz and mica is not apparent megascopically, though extensive neomineralization is commonly apparent without the aid of a thin section. For these reasons Knopf's distinction between recrystallization and neomineralization is used in the definitions here, and a mylonite may contain recrystallized quartz and mica, but does not show significant neomineralization of the pre-existing minerals.

The terminology for cataclastic rocks used here is as follows:

Mylonite: A coherent, aphanitic microbreccia, with or without lamination, in which neomineraliation (of Knopf, 1931) is minor, but quartz and biotite may be recrystallized. A few porphyroclasts of uncrushed mineral grains or rock fragments may be present.

Mylonite gneiss: Similar to mylonite except that porphyroclasts form 10-90 per cent of the rock (See Bryant and Reed, in press).

Blastomylonite: A fine grained, cataclastic rock, with or without lamination in which neomineralization (of Knopf, 1931) is far enough advanced that cataclastic textures are difficult to recognize. The most common new minerals are chlorite and actinolite from the pre-existing mafic minerals and sericite, epidote, calcite and albite from pre-existing feldspars. Possibly some pods of amphibolite which are surrounded by by cataclastic rocks but which do not themselves show cataclastic textures are blastomylonites.

Ultramylonite: A cryptocrystalline, commonly dark-colored, structureless cataclastic rock, which occurs as thin (commonly less than 1 inch) sill- or dike-like stringers in the other cataclastic rocks. The rock is similar to pseudotachylyte, except that there is no indication of fusion.

Mortar gneiss: A partially cataclastic rock in which granulation is primarily along grain boundaries, or as streaks or lenses between bands of ungranulated rock (See Bryant and Reed, in press).

Porphyroclast: A relict mineral grain or, less commonly rock fragment, in a fine grained granulated matrix. The matrix may or may not be recrystallized or neomineralized, but the relict grain or fragment is not.

The definitions given here in general follow those of Knopf (1931, p. 13). The terms may differ from their usage in previous Connecticut reports (Snyder, 1961, 1964a; Lundgren, 1962, 1963, 1966a), but the terms have not been defined in any of these earlier reports. Lundgren (1962, p. 19) refers to "extensively crushed, though largely recrystallized blastomylonite gneisses", and later compares the mineral assemblages of the uncrushed rocks with those of the crushed and recrystallized rocks, suggesting his use of blastomylonite is in general similar the use here. Snyder (1961) states: "Most of the blastomylonites are very-fine-grained biotite gneiss without any later alteration minerals" though elsewhere in the same report he refers to "Blastomylonites with recrystallized biotite and muscovite".

Grain size is not used as a factor in the definitions of the various rocks, other than that schists are not so fine grained as to be classed as phyllites. The rock name is, instead, qualified by a general grain size designation. The grain size designations used here follow those given by Niggli (1954, p. 197) and are as follows: very fine grained is less than 0.1 mm, fine grained is 0.1 to 0.33 mm, small grained is 0.33 to 1 mm, medium grained is 1 to 3 mm, and coarse grained is greater than 3 mm. Rocks with an average grain size greater than 1 mm are rare in this area. The average grain size given for various rocks is based on the equigranular minerals, primarily quartz, feldspar and amphibole. A range in the average grain size given for some rock units indicates that different layers within the unit have different average grain sizes; some have the lower value, some the upper value and others are between the two values. An average grain size for the mortar gneisses is difficult to determine, and of questionable significance, and for these rocks the grain size is commonly designated as variable.

Color terms used for both rocks and minerals are the terms of the Rock-Color Chart issued by the National Research Council (1948). The colors cited are the closest match between the color chips and the indicated rock or mineral. The color charts have been used both for megascopic rock and mineral colors and for microscopic mineral colors. The color formula (as moderate brown, 5 YR 4/4) is used only for describing a specific mineral, as in the tables of modes.

Petrographic study involved examination of about 900 thin sections. Modal analyses were determined by point counting using a Chayes type mechanical stage. Between 1000 and 1500 points were counted along evenly spaced traverses across the thin section. The approximate composition of the plagioclase was determined by extinction angles on grains perpendicular to a bisectrix, and plotted on the curves of Tröger (1956, p. 101).

Optical properties of a few of the minerals were determined by use of the spindle stage. Refractive indices were measured by the method of Wilcox (1959) and optic angles by the method of Wilcox and Izett (1968).

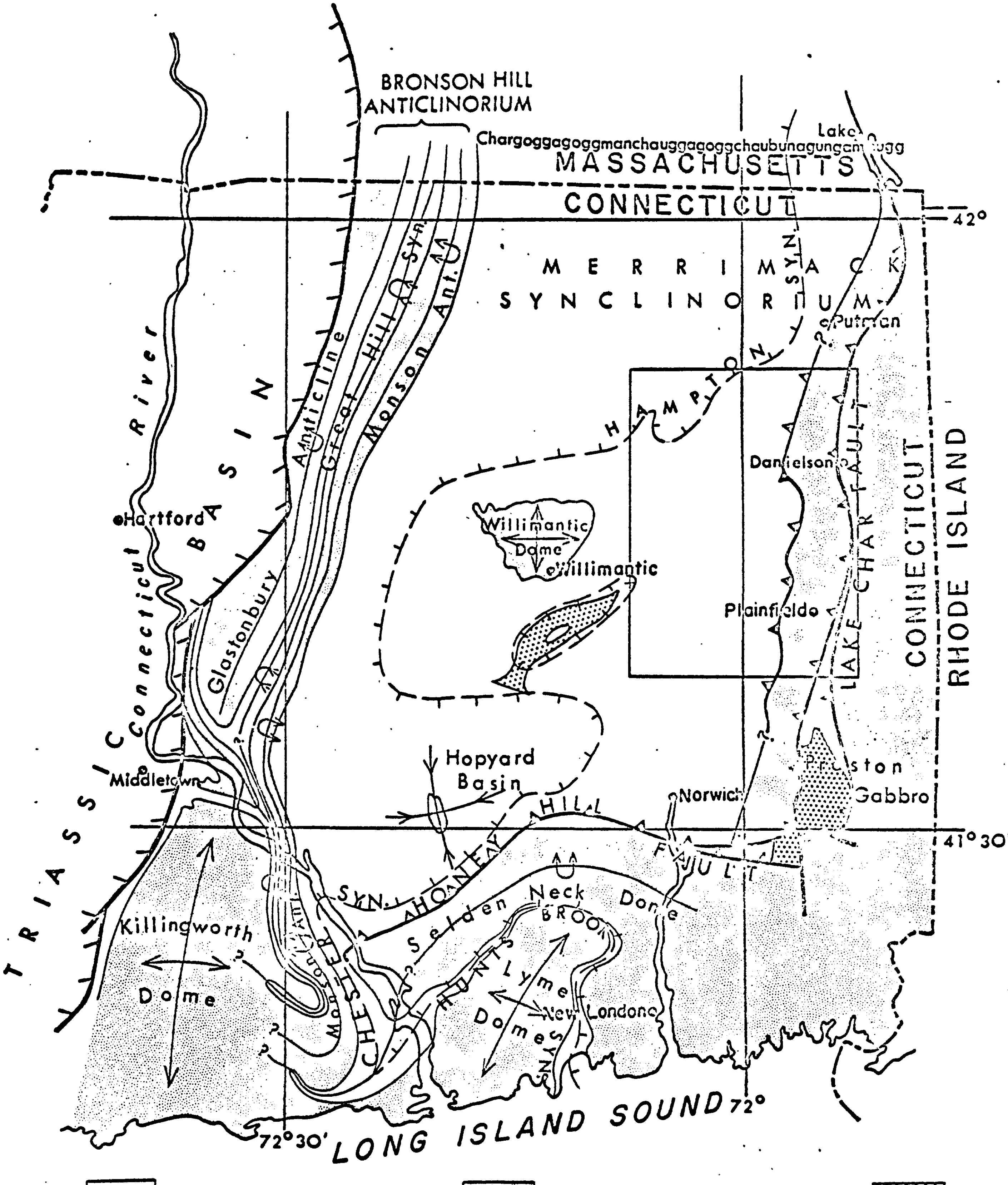
The chemical analyses which are reported with the various rock units were put through a computer and recalculated to a C.I.P.W. norm, Barth cation percentages, Niggli numbers and various sets of oxide and feldspar ratios. The C.I.P.W. norms are recorded only with the analyses of rocks of igneous rock composition, including the metavolcanic rocks. For all analyses the Barth cation per cents were recalculated into mesonorms using the methods and standard normative mineral formulae of Barth (1959, 1962), though with some variations depending on the rock. For all analyses instead of subtracting H and recalculating to 100 percent, H is reported as water (H_2O). Water is present in several hydrous minerals which are not calculated into the norm, such as sericite, staurolite and epidote, and it seemed advisable to retain the standard formulae of the hydrous minerals as given by Barth, rather than calculating water into them, and to leave the water as water. In many of these rocks muscovite is common and potassium feldspar is not; for these rocks excess K (over than combined with Fe+Mg for biotite) is converted to muscovite by the formula $KAl_3Si_3O_{10}$. Ti is combined with an equal amount of Ca and Si as sphene for all samples except the micaceous schists and gneisses of the Tatnic Hill Formation and the Scotland Schist (tables 13 and 14) as sphene is not a phase in these rocks; Ti in these samples is combined with Fe to form ilmenite.

In the tables and in the text, sample numbers for rock samples are preceded by an initial designating the quadrangle from which the sample was collected. Thus a D indicates a sample from the Danielson quadrangle, H from the Hampton quadrangle, P from the Plainfield quadrangle, S from Scotland quadrangle, T from Thompson quadrangle and E from East Killingly quadrangle. The sample numbers of samples from the collection of G. Neuerberg from the Plainfield quadrangle are preceded by PN.

The location of samples cited in the tables and exposures described in the text is given as thousands of feet north and west of the southeast corner of the respective quadrangles, using an initial to designate the quadrangle. Thus a location of D-27.7 N; 0.5 W indicates an outcrop 27,700 feet north and 500 feet west of the southeast corner of the Danielson quadrangle.

REGIONAL GEOLOGY

The central portion of eastern Connecticut represents the southern limit of the Merrimack synclinorium as mapped in New Hampshire by Billings (1956). As in New Hampshire, the synclinorium is bordered on the west by the Bronson Hill anticlinorium, which in Connecticut consists of the Monson and Glastonbury anticlines and the intervening Great Hill syncline (see fig. 2). On the south and east the synclinorium is cut off by the Honey Hill-Lake Char thrust fault, and the extension of the Lake Char fault northward probably bounds the synclinorium across most of eastern Massachusetts (Novotny, 1961). The internal structure within the synclinorium is interpreted to be a large recumbent syncline, overturned to the east (Dixon and Lundgren, in press). The recumbent syncline can be traced from the upper plate of the thrust fault, around the western end of the Honey Hill fault and into the lower plate. The Willimantic dome forms a large, open structure about in the center of the Connecticut portion of the synclinorium. It differs from the domes of the Bronson Hill anticlinorium, which are elongate north-south structures, in that the core is about circular in outline. The major structural features of eastern Connecticut are shown on the tectonic map (fig. 2). The geologic map of eastern Connecticut (plate 1) was compiled from recent mapping in the area by Goldsmith (1963) and was revised and updated for this report. The fence diagram in plate 2 illustrates the interpreted structural relationships in and around the Connecticut portion of the Merrimack synclinorium.



Mid. Ordovician and younger metasedimentary rocks and intrusive gneisses

Mid. Ordovician and older metavolcanic and metasedimentary rocks and granitic gneisses

Gabbro

Figure 2.--Tectonic map of Eastern Connecticut: the Plainfield-Danielson area is outlined. The trace of the axial surface of the Hunts Brook-Chester-Hampton syncline is shown by a dashed line; ticks are on the recumbent limb.

The structural and stratigraphic sequences of the various bedrock units of eastern Connecticut are shown in table 1. Also given in the table are the radiometric ages which have been determined for some of the units. Whether or not these numbers do, in fact, represent the real age of the rocks is questionable. The numbers of Brookins and Hurley (1965) for the units west of the Monson anticline are low for a probable middle Ordovician age, but they do support the field evidence of the relative ages of these units.

The stratigraphic succession of units in the area is fairly well established west of the Monson anticline, south of the Honey Hill fault, and on the east above the Lake Char fault. The youngest rocks of the area are the Siluro-Devonian rocks of the Bolton Group of Rodgers et al (1959) in the Great Hill syncline. These rocks have been traced north across Massachusetts to correlate with the Clough, Fitch, and Littleton Formations of New Hampshire (Rodgers et al, 1959; Eaton and Rosenfeld, 1960). Unconformably beneath the Bolton Group are successively the Brimfield Schist, Middletown Formation and Monson Gneiss. Brimfield and Middletown are correlated respectively with the Partridge Formation and Ammonoosuc Volcanics of middle(?) Ordovician age in New Hampshire (Cady, 1960; Billings, 1956). Monson is gradational into Middletown, and where the anthophyllitic gneiss characteristic of the Middletown is not present, the two are difficult to distinguish (Lundgren, 1963). Monson Gneiss occupies the core of the Monson anticline and of the Killingworth dome. Older rocks are observed to the south in the domes and complex folds south and west of the Honey Hill fault. In these structures Monson is underlain successively by the New London Gneiss, Mamacoke Formation and Plainfield Formation, all of which are intruded by or interlain with granitic gneiss and alaskite of the Sterling Plutonic Group (Goldsmith, 1966).

Table 1.--Possible correlations and ages of rocks in eastern Connecticut

	N. Hamp. & Central Mass.	W. of Monson anticline		E. of Monson anticline alternative correlations					
Low. Dev.	Littleton Fm.	Littleton Fm.	Glastonbury Gneiss (355 ± 10)1/	Bolton Group of Rodgers, et al (1959)			Canterbury Gneiss (430 ± 20)2/	Scotland Sch	Scotland Sch quartzite
Mid. Sil.	Fitch Fm.	Fitch Fm.							Hebron
Low. Sil.	Clough Qtzite	Clough Qtzite						quartzite	
T A C O N I C U N C O N F O R M I T Y - -				- - - ? - - - - ?					
				(Reverse sequence in E. limb of Monson anticline)	(Structural sequences around Willimantic dome area)	Scotland Sch quartzite Hebron Fm.		Hebron Fm.	
Mid.(?) Ord.	Partridge Fm.	Brimfield Sch (390 ± 40)1/		Brimfield Sch	Brimfield Sch Brimfield Sch Hebron Fm. Tatnic Hill Fm.	T a t n i c		H i l l	F o r m a t i o n
Mid. Ord.	Ammonoosuc Volc. (418 ± 15)1/	Middletown Fm. (440 ± 15)1/ Monson Gn. (472 ± 15)1/		Middletown Fm. Monson Gn.	Monson Gn. - - - Quinebaug Fm.	Q u i n e b a u g			F o r m a t i o n
		New London Gn. Mamacoke Gn.			Sterling Plutonic Group			F a u l t	
Camb.(?)		Plainfield Fm.				P l a i n f i e l d			F o r m a t i o n

1/ Whole rock Rb/Sr ages of Brookins and Hurley (1965)
2/ Whole rock Rb/Sr ages of Zartman et al (1966)

The Plainfield Formation is the oldest bedrock unit recognized in eastern Connecticut (Lundgren, 1967).

The core of the Monson anticline is steep to overturned to the east, and the degree of overturning increases to the north. On the eastern, or overturned flank of the anticline the sequence of units is Monson Gneiss over Middletown Formation over Brimfield Schist. In the central part of the area the sequence of Middletown over Brimfield over Hebron Formation is observed in the Hopyard basin (Lundgren, 1966a) and to the north the main mass of Brimfield overlies Hebron (plate 1). Further east, in and around the Plainfield-Danielson area, the sequence of units is Scotland Schist over Hebron Formation over Tatnic Hill Formation over Quinebaug Formation; this sequence can be demonstrated to be right side up by a few preserved sedimentary structures. The fact that both Brimfield and Scotland overlie Hebron Formation, and that both are largely micaceous schists led Foye (1934, 1949) to conclude that the two units are the same rock. Recent mapping indicates, however, that the Tatnic Hill Formation, not the Scotland Schist, is correlative with the Brimfield. The Tatnic Hill can be traced from the Fitchville quadrangle southwest above the Honey Hill fault into the east limb of the Chester syncline (Snyder, 1964a; Lundgren, 1963, 1966a). Brimfield Schist, likewise, can be traced southward from the main belt, and from the Hopyard basin, along the east flank of the Monson anticline into the west limb of the Chester syncline (plate 1). A few miles north of the coast, where the Chester syncline is folded around the Selden Neck dome, the Hebron in the core of the syncline plunges out, and the Tatnic Hill and Brimfield make up the core of the eastern extension of the syncline, where it is known as the Hunts Brook syncline (Goldsmith, 1961). The Tatnic Hill is therefore correlated with the Brimfield, and the sequence of Middletown over Brimfield over Hebron is interpreted to be a reverse, or up-side-down sequence.

The Hunts Brook-Chester-Hampton syncline constitutes the major overturned syncline in the center of the Merrimack synclinorium; the Hampton syncline designates the extension of the fold in the Plainfield-Danielson area. The core of the Hunts Brook syncline is Brimfield Schist and Tatnic Hill Formation, and is flanked by Monson Gneiss and older rocks symmetrically arranged on either side, although some units are very thin on the south side (Goldsmith, 1961). West of the Connecticut River the axial surface of the fold is refolded around the Selden Neck dome (see fence diagram, plate 1), and it traces northward as the steep, seemingly simple Chester syncline. The core of the Chester syncline is Hebron Formation, and is flanked by the Tatnic Hill and Monson on the east, and by Brimfield, locally Middletown, and Monson on the west. The core of the Hampton syncline is partly Hebron Formation and partly Scotland Schist, and is flanked by Tatnic Hill and Quinebaug Formations on the east and by Brimfield, Middletown and Monson on the west. The axial surface of the syncline thus goes successively through Tatnic Hill-Brimfield, Hebron and Scotland. The trace of the axial surface is well established in the Hunts Brook syncline and the steep part of the Chester syncline west of the Connecticut River, but it is not so well located in the recumbent part of the fold. North of the Honey Hill fault and east of the Connecticut River, it must trace east through the Hebron between the Brimfield of the Hopyard basin and the Honey Hill fault. To the east the trace may go through the isoclinal belt of Scotland Schist in the Fitchville quadrangle (Snyder, 1964a), or it may stay in the Hebron, in which case the Scotland is in a smaller fold on the normal limb of the recumbent fold. The axial surface must be warped up over the Willimantic dome (plate 1), so that the trace wraps around the south, west and north sides of the dome, and is in Hebron throughout this area. Northeast of the dome, Scotland Schist is in the core of the fold again, and the trace remains in the Scotland most of the rest of the distance it has been followed.

The major thrust fault that borders the Connecticut portion of the Merrimack synclinorium has been mapped in two segments, both of which are traced primarily by intense cataclasis of the rocks on and near the fault plane. The Honey Hill fault has been traced from west of the Connecticut River east to the Preston Gabbro area. The Lake Chargoggagoggmanchaugga-goggchaubunagungamaugg fault (henceforth referred to as the Lake Char fault) has been traced from Lake Chargoggagoggmanchauggagoggchaubunagungamaugg in southern Massachusetts southward to the Preston Gabbro (see fig. 2). The area of the gabbro has not yet been adequately mapped, but reconnaissance in that area indicates that the Honey Hill and Lake Char segments are continuous around the gabbro, and form a single fault plane. North and west of the gabbro the fault splits into two main branches, one of which goes above the gabbro and the other goes beneath it. The lower thrust plane, which puts gabbro and Quinebaug Formation over Plainfield Formation and Sterling Plutonic Group is the one of major displacement.

The Honey Hill-Lake Char fault is a gently, northwest to west dipping surface. So far as can be determined within the limit of exposure it consists of a single plane which separates the Tatnic Hill Formation (above the Honey Hill fault) and the Quinebaug Formation (above the Lake Char fault) from the Monson Gneiss (below the Honey Hill fault) and the Plainfield Formation (below the Lake Char fault) and interleaved gneisses of the Sterling Plutonic Group. There are numerous smaller thrust faults both above and below the main fault plane, but only very locally does there appear to be a zone of imbricate faults in which rock types of the upper and lower plate are intermixed.

Movement on the Honey Hill-Lake Char fault was apparently from northwest to southeast. This is indicated by large, west plunging drag folds in the upper plate of the fault in the Fitchville quadrangle (Snyder, 1964a) and by a persistent N. 60° to 70° W. mineral lineation in the cataclastic rocks along the Lake Char fault. The amount of displacement cannot be determined. Displacement appears to increase to the east along the Honey Hill segment and to the north along the Lake Char segment. Throughout most of the length of the fault trace, the structures of the rocks above and below the fault are subparallel to the fault plane. Sharp truncation of units along the fault is observed only along the eastern part of the Honey Hill fault in the Fitchville (Snyder, 1964a), Norwich (Snyder, 1961) and Uncasville (Goldsmith, 1967a) quadrangles, where the lower part of the Tatnic Hill and the Quinebaug Formations are cut off. The Lake Char fault apparently truncates the Quinebaug Formation in the upper plate at a low angle, as the Quinebaug appears to be thinning to the north, and reconnaissance around Lake Chargoggagoggmanchaugga-goggchaubunagungamaugg suggests that north of the lake it might be cut out entirely.

Several lines of evidence indicate a general sequence of tectonic events in the area, though the exact sequence is not well established. There were at least two major periods of folding; faulting probably started during the second stage of folding and continued after folding. Regional metamorphism probably reached a peak during the early stages of folding, but the area apparently was still warm at the outset of cataclastic deformation and the early stages of movement on the thrust faults.

If the structural picture shown in the fence diagram of plate 8 is essentially correct, the major Hunts Brook-Chester-Hampton syncline was formed fairly early in the tectonic history, and was subsequently refolded around the Selden Neck dome, during which the upper limb of the refold was overturned to the east. The Monson anticline would represent the core of the anticline lying above or west of the overturned syncline. The recumbent portion of the overlying anticline apparently has been eroded away in Connecticut, though the Brimfield Schist area in northern Connecticut and Massachusetts has not yet been mapped, and rocks equivalent to the Middletown or Monson may locally overlie Brimfield in that area. If the corollary anticline was present beneath, or on the east side of the syncline, it has apparently been overridden by the Honey Hill fault.

The axial plane of the Selden Neck dome is essentially parallel to the Honey Hill fault, and it is probable that movement on the fault plane was contemporaneous with refolding around the dome. Cataclastic rocks occur locally near the axial plane of the Chester-Hampton syncline, near the overturned Hebron-Brimfield contact and in the Brimfield. These suggest subsidiary thrusting in the overturned structure during refolding, or during the push eastward. Cataclasis of metamorphosed rocks, folding of early formed cataclastic rocks (Snyder, 1964a, Lundgren, 1963), and truncation of metamorphic isograds (Snyder, 1964a, 1961) all indicate faulting took place over a long period of time, and continued after other tectonism stopped.

GENERAL GEOLOGY

The Plainfield-Danielson area lies near the eastern edge of the Connecticut portion of the Merrimack synclinorium. Within the area a section of rock having a maximum thickness of about 15,000 feet is exposed in the upper plate of the Lake Char thrust fault and the normal limb of the recumbent Hampton syncline (plates 1 and 6, fig. 3). The Lake Char fault traces along the eastern side of the Plainfield and Danielson quadrangles (plates 2 and 4), and only a few of the gneisses of the lower plate are exposed near the eastern boundary of the area. The trace of the axial surface of the Hampton syncline goes through the northern part of the Hampton quadrangle and the northwestern corner of the Danielson quadrangle (plates 2 and 3) and the rocks north of this trace are in the overturned limb of the syncline.

Rock units in the lower plate of the Lake Char fault consist of thin layers of the Plainfield Formation interleaved with biotite quartz monzonite gneiss and alaskite gneiss of the Sterling Plutonic Group. In this area the Plainfield is primarily quartzite with lesser amounts of hornblende gneiss, actinolite gneiss and quartz-mica schist. The Plainfield is provisionally dated as Cambrian(?) (Goldsmith, 1966) as southwest of this area it underlies probable middle Ordovician metavolcanic rocks. The Sterling gneisses include the Hope Valley Alaskite and the Scituate Granite Gneiss. The age of the rocks of the Sterling Plutonic Group has not been established except that they are older than the Pennsylvanian rocks in the Narragansett Basin of Rhode Island (Quinn, 1951).

In the upper plate of the Lake Char fault the stratigraphic units, from oldest to youngest include the Quinebaug Formation, Tatnic Hill Formation, Hebron Formation and the Scotland Schist. The Quinebaug and Tatnic Hill

Possible Age	Formation	Member	Lithology	Description	Thickness (in feet)
ORDOVICIAN TO DEVONIAN	Scotland Schist			Non-rusty, medium-gray garnet-muscovite schist; at base quartzose granular schist, locally quartzite.	800+
ORDOVICIAN TO SILURIAN	Hebron Formation			Thinly layered, dark-, purplish-or greenish-gray, fine-grained calc-silicate schist and biotite schist.	500-1000
MIDDLE (?) ORDOVICIAN	Tatnic Hill Formation	Yantic member		Dark-gray, small-grained binary schist; commonly with coarse plagioclase; lenses of amphibolite near the base.	800-1200
		Fly Pond member		Medium-gray, layered calc-silicate gneiss.	125-600
		Lower member		Metasedimentary medium-, dark- or greenish-gray, small-grained micaceous gneiss. Local binary gneiss at top; sillimantic binary gneiss most abundant; in lower part garnet-biotite gneiss and at base rusty weathering sillimanitic gneiss. Lenses of amphibolite mostly near base; lenses of calc-silicate gneiss, commonly small but locally 300 feet thick.	4500
MIDDLE ORDOVICIAN	Quinebaug Formation	Upper Member		Metavolcanic medium- to dark-gray, fine-grained well layered hornblende gneiss, biotite gneiss and amphibolite.	750-2000
		Black Hill member		Lens of light-gray, fine-grained laminated tonalitic gneiss 0-1400 feet thick.	1500±
				Metasedimentary, light- to dark-gray, fine-grained well-layered biotite schist hornblende gneiss, muscovite gneiss, commonly with calcite; minor sillimanite schist.	
		Lower member		Similar to upper member; minor pods of sillimanite-muscovite gneiss. In this area all is cataclastic and near the base rocks are mylonite, mylonite gneiss and blastomylonite.	750-4000
	FAULT				
CAMBRIAN (?)	Plainfield Formation			Mylonitic, light-gray, or buff quartzite, mica quartz schist and hornblende gneiss.	

Figure 3.--Stratigraphic sequence in the Plainfield-Danielson area.

Formations make up the Putnam Gneiss of Gregory (in Rice and Gregory, 1906) and are now included as formations in the Putnam Group (Dixon, 1964). The Quinebaug Formation consists of interlayered hornblende gneiss, biotite gneiss and amphibolite of metavolcanic origin, and subordinate amounts of micaceous gneiss, some containing sillimanite, and calc-silicate rocks of metasedimentary origin. The rocks overlying the Quinebaug are a series of metasedimentary rocks, mainly micaceous gneisses and schists and calc-silicate rocks. The Tatnic Hill Formation is made up mostly of various mica schists and gneisses, with lesser amounts of interlayered calc-silicate gneiss, although one mappable unit of calc-silicate gneiss is separated as the Fly Pond Member. The Hebron Formation is a unit of thinly layered calc-silicate schist and biotite schist. The Scotland Schist consists mainly of coarse muscovite schist and minor quartzite.

Rock units in the overturned limb of the Hampton syncline include the Scotland Schist, Hebron Formation and Brimfield Formation. The Hebron Formation in the overturned limb differs from that in the normal limb in that it contains a higher proportion of biotite schist and less interlayered calc-silicate schist, and the rocks commonly are less thinly layered. The Brimfield which underlies the extreme northwest corner of the Hampton quadrangle is not exposed in the area, but is exposed in the Spring Hill and Eastford quadrangles to the west and north.

Gregory (in Rice and Gregory, 1906) described two units, the Pomfret Phyllite and the Woodstock Quartz Schist, in the northern part of the Hampton and Danielson quadrangles. Rocks in this area are here mapped as either Scotland Schist or Hebron Formation, and the names Pomfret Phyllite and Woodstock Quartz Schist are dropped as useful names in eastern Connecticut.

The Pomfret Phyllite as delineated on the geologic map of Rice and Gregory (1906) includes both Hebron Formation and Scotland Schist, and Gregory's description of Pomfret suggests he included rocks of both units. The Pomfret is described as: "....phyllite is well foliated, the foliation planes being made of minute flakes of mica, which give the rock a purplish tone and a silky luster....this formation also exhibits distinctly schistose varieties, containing much muscovite in fairly large plates...." (Rice and Gregory, 1906, p. 129). The first part of the description sounds like Hebron as here mapped, and the latter part sounds like Scotland, though there are thin lenses of muscovite schist in the Hebron. Foye (1949) does not separate Pomfret Phyllite from Hebron on his map, but has a separate discussion (p. 80-81) in which he equates Pomfret with the Worcester Phyllite of Massachusetts. He cites three "best outcrops" of Pomfret, all of which are in the Putnam quadrangle. Preliminary mapping in the Putnam quadrangle has shown that two of these outcrops are in the Hebron Formation and one is in Scotland Schist. Probably the exposures which prompted the name Pomfret Phyllite were of the extremely rusty weathering, graphitic muscovite schist which occurs locally in the Hebron.

The Woodstock Quartz Schist is shown on the map of Rice and Gregory (1906) between the Pomfret Phyllite on the east and the Brimfield Schist on the west. This is primarily the area of the biotite-quartz-plagioclase schist and interlayered calc-silicate schist of the Hebron Formation in the overturned limb of the Hampton syncline. The rocks in the area included in the Woodstock Quartz Schist can be traced continuously south-west to typical Hebron schists in the area of Hebron.

Two large biotite granodiorite to quartz monzonite sills occur primarily in the Hebron Formation, but locally cut across it to the upper part of the Tatnic Hill below or into the Scotland Schist above. The Canterbury Gneiss is in the normal limb of the recumbent Hampton syncline and the Eastford Gneiss is in the overturned limb. The two sills are probably genetically related, but there are compositional differences between the rocks.

There is no direct evidence in Connecticut for the age of the rocks and age assignments are based primarily on correlations. The Tatnic Hill Formation in the normal limb of the Hampton syncline is correlated with the Brimfield Schist in the overturned limb, and in the central and western part of eastern Connecticut Brimfield is correlated with the Partridge Formation of New Hampshire of middle Ordovician age (Billings, 1956; Cady, 1960). The underlying Quinebaug Formation is correlated with the metavolcanic rocks of the Middletown Formation and Monson Gneiss; Middletown Formation is correlated with the Ammonoosuc Volcanics of New Hampshire, of middle Ordovician age (Billings, 1956; Cady, 1960). Thus the Quinebaug Formation, the Tatnic Hill Formation and the Brimfield Schist of this area are provisionally dated as middle Ordovician. The Hebron Formation and Scotland Schist are younger than the Tatnic Hill, and could be middle or upper Ordovician or could be as young as lower Devonian (see table 1). The Canterbury and Eastford Gneisses cut the Hebron Formation, and apparently also Scotland Schist, and must be younger than these rocks. A radiometric age on the Canterbury Gneiss (Zartman et al, 1965) suggests an upper Ordovician or Silurian age for the Canterbury, if the number does, in fact, date the emplacement of the gneiss.

All the rocks of this area were regionally metamorphosed to upper amphibolite facies, subjected to at least two major periods of folding and an extended period of cataclastic deformation and faulting. The major period of deformation was probably during the post-lower Devonian Acadian orogeny. Pre-Acadian folding may have affected the Ordovician rocks, but if so it is not yet possible to distinguish the pre-Acadian folds from the Acadian folds. During the Acadian deformation the rocks were folded into the Hampton syncline; regional metamorphism probably accompanied this stage of folding. During subsequent deformation the Hampton syncline was overturned to the east, and the rocks of the Tatnic Hill Formation, Quinebaug Formation, Plainfield Formation and Sterling Plutonic Group were cataclastically deformed, and faulted along the Lake Char and subsidiary thrust faults. This later deformation may have started during the final stages of the Acadian orogeny, but movement on the faults continued beyond any other tectonic activity in the area and may have continued into the Permian. The rocks of eastern Connecticut are within the area of the 250 m.y. event which affected the K/Ar mica ages throughout much of southern New England (Faul, et al, 1963; Zartman, et al, 1965). Late stages of deformation in this area may, therefore, be related to this event.

Eastern Connecticut was covered by at least one major ice sheet during the Pleistocene glaciation. Pessl (1966) believes he has evidence for two tills, and thus two glacial advances, in a quarry just north of the Hampton quadrangle. Glaciofluvial deposits are found in the valleys of several streams, but the only major glaciofluvial drainage system in the area is the valley of the Quinebaug River. The upland areas are covered by a blanket of till which is commonly 5 to 10 feet thick, and conforms to the bedrock topography. Drumlins, with their own topographic expression, occur principally in the northwestern corner of the Scotland and the northern part of the Hampton quadrangles.

DESCRIPTIONS OF THE STRATIGRAPHIC UNITS

Plainfield Formation

The Plainfield Formation in the Plainfield-Danielson area consists of lenses of predominately quartz rich rock interleaved with the Sterling Plutonic Group in the lower plate of the Lake Char fault. In the two main belts of Plainfield Formation shown on plate 6 the most prominent rock is quartzite, with subsidiary amounts of quartz-mica schist, hornblende gneiss and actinolite gneiss. The third area, between two slices of the thrust fault is tentatively assigned to the Plainfield Formation, and is made up almost entirely of hornblende gneiss and amphibolite.

The Plainfield Quartz Schist was named by Gregory (in Rice and Gregory, 1906) for exposures in the town of Plainfield. The unit is, however, better exposed in other places than in Plainfield and Lundgren (1963, 1964) and Goldsmith (1966) redefined the unit as the Plainfield Formation on the basis of exposures southwest of this area, retaining the name Plainfield because of common usage. Gregory (in Rice and Gregory, 1906) and Loughlin (1912) and Foye (1949) failed to recognize the presence of the Lake Char thrust fault between the Plainfield Formation and the overlying Putnam Group, and thought the Plainfield represented the base of the Putnam. Because rocks of the same general lithology, that is biotite gneiss and hornblende gneiss, occur in both units, they considered the Plainfield to be gradational into the Putnam.

The Plainfield Formation is a prominent unit along the eastern and southern edges of eastern Connecticut. It is however, so abundantly interleaved with sills of the Sterling Plutonic Group that a complete section cannot be seen in any one area, with the possible exception of the East Killingly and Thompson quadrangles, where detailed mapping is not completed. On the basis of the regional pattern Goldsmith (1966) divided the Plainfield into three parts; the upper and lower parts are characterized by thickly layered quartzite with minor mica-quartz schist, calc-silicate gneiss, and feldspathic quartzite, and the middle part consists of interlayered quartz-feldspar gneiss with sillimanite or with hornblende and diopside, calc-silicate quartzite and gneiss, amphibolite, garnet schist and subordinate quartzite. Lundgren (1967, p. 14-15) describes the lower unit of the Plainfield in the core of the Lyme Dome as consisting primarily of biotitic or hornblendic quartz-feldspar gneiss. G. Moore (personal communication, 1966) also recognized these three subdivisions within the Plainfield Formation in the East Killingly quadrangle. The two main belts of Plainfield in the Plainfield and Danielson quadrangles are continuous with the larger mass of Plainfield in East Killingly, and thus are apparently part of the upper part of the formation.

The thickness and contact relations of the Plainfield Formation cannot be determined within the Plainfield and Danielson quadrangles, since such a limited part of the unit occurs here. Individual belts of the formation have a maximum thickness of about 800 feet, though commonly they are much thinner. A contact between the Plainfield and the Hope Valley Alaskite is exposed in Ekonk Brook south of Moosup (P-31 N; 0.5 W), but both rocks here are strongly cataclastic and the original nature of the contact cannot be determined. The grade of metamorhism of the rocks prior to cataclasis also cannot be determined within the area. About 2 1/2 miles east of the Danielson quadrangle, in East Killingly, sillimanite, kyanite and staurolite have been observed in the mica-quartz schist of the Plainfield Formation, and it is reasonable to assume that the rocks in the Plainfield and Danielson quadrangles were sillimanite or kyanite grade.

All the Plainfield Formation in the Plainfield and Danielson quadrangles is close to the Lake Char thrust fault and has been cataclastically deformed during movement on the fault. A description of the rocks of this area cannot, therefore, be considered to be characteristic of the unit, or even of the small part of the unit which occurs in this area. Some of the Plainfield Formation in the Thompson quadrangle is far enough away from the fault that it is not cataclastic. The rocks there are predominantly medium grained, light gray, weathering grayish-orange quartzite and medium to coarse grained, silver-gray mica-quartz schist. A thin section of a quartzite from the Thompson quadrangle showed the quartz has an average grain size of 0.7 mm and occurs as granular grains with little or no suturing of grain boundaries (plate 7, fig. 1). A modal analysis of this sample is given in table 2. Both plagioclase and potassium feldspar are very fine grained, and plagioclase is too altered to sericite to determine its composition, but the refractive index is about the same as quartz and it is probably about oligoclase. Biotite is also strongly altered to chlorite and limonite.

Belt in the southern half of the Plainfield quadrangle.--(Plate 4 and plate 6). The belt of Plainfield Formation in the southern part of the Plainfield quadrangle was originally mapped as two separate, thin belts (plate 4). Work by D. Harwood (written communication, 1968) in the adjacent parts of the Oneco quadrangle has shown, however, that east of Moosup the belt of quartzite and quartz-mica schist is wider and more extensive than was previously thought, and that the southern contact between the Plainfield and the Hope Valley Alaskite must be about a mile south of where it is located on the Plainfield map (plate 4). It therefore seems likely that the Plainfield Formation in this area forms a continuous belt.

The belt has a maximum thickness of about 800 feet in the Oneco quadrangle (Harwood, written communication, 1968) and apparently thins to the south. The rocks in general trend north or northeast and dip about 25° west.

Directly beneath the Lake Char fault surface west of Starkweather Road (P-25 N; 5 E) are a few exposures of quartzite mylonite or blastomylonite. The rock is extremely fine grained, thinly laminated and grayish yellow green to very light gray (plate 7, fig. 3). In one small exposure the rock looks like a breccia except that the very fine-grained matrix is apparently mostly quartz and is strongly indurated. The clasts are rounded to angular, fine-grained cataclastic quartzite and quartz-chlorite rock, and have a maximum size of about 1/2 inch.

Away from the fault the average grain size of the quartzite increases to about 0.2 mm. The rock is very light gray, pinkish gray, or grayish orange, and is massive to thinly laminated. The quartzite typically contains 75 to 90 percent quartz, and secondary amounts of plagioclase, potassium feldspar, muscovite and biotite, and accessory amounts of opaque minerals zircon and apatite (sample P2-262, table 2). Either or both plagioclase and potassium feldspar may be present; both are very fine grained and untwinned. Biotite in some samples is very pale orange, and difficult to distinguish from muscovite, and in others it is light brown. Quartz grains are commonly elongated (in P2-262 the length to width ratio is about 2:1; plate 7, fig. 2), and show moderate to strong suturing of grain boundaries.

The exposures near the southern limit of this belt contain very-fine-grained light-gray quartzite interlayered with fine-grained, dark-gray hornblende gneiss (sample P2-172, table 2). The hornblende gneiss is thinly laminated with discontinuous light-gray streaks of quartz and feldspar. The average grain size is about 0.2 mm. Quartz shows moderately strong undulose extinction and suturing of grain boundaries. The plagioclase is probably about andesine, but the grains are too small and too much altered to determine their composition. In general the hornblende gneiss resembles cataclastic rocks of similar composition in the Quinebaug Formation, but the interlayered quartzite was not observed in the Quinebaug.

Belt along the eastern edge of the Danielson quadrangle.--The second belt of Plainfield Formation can be traced from the northeastern corner of the Plainfield quadrangle (plate 4) to the northern part of the Danielson quadrangle (plate 5). Most of the exposures in this belt are of quartzite which is in general similar to the quartzite in the southern belt. Other lighologies were observed primarily in Whetstone Brook (D-29.7 N; 0.5 E) where the quartzite is associated with medium gray, thinly laminated muscovite-biotite-quartz schist, greenish-gray quartz-actinolite gneiss and blueish-gray actinolite quartzite (sample D5-14, table 2). The The laminations in the quartz schist and the actinolite gneiss are tightly isoclinally folded

All the rocks of this belt in the Plainfield and Danielson quadrangles are mylonite or blastomylonite. Average grain size in all the samples studied is less than 0.1 mm. Quartz boundaries are moderately to strongly sutured. A sample of quartzite mylonite from exposures along the Connecticut Turnpike near the western edge of the East Killingly quadrangle contains rounded quartz grains set in an ultrafine-grained matrix which is apparently a mixture of quartz and clay (plate 7, fig. 4; plate 8, fig. 1 and 2). The quartzite mylonite which occurs within a foot or two of the Lake Char fault plane is a laminated, light-olive-gray or greenish-gray rock which is difficult to distinguish from alaskite mylonite.

Belt of Plainfield(?) Formation in the slice between two thrust faults, Danielson quadrangle.--(Plates 2, 6). The hornblende gneiss and amphibolite which is provisionally assigned to the Plainfield Formation on plate 6 was originally assigned to the Quinebaug Formation (plate ~~4~~ 2). The rocks occur between the Lake Char thrust fault and a subsidiary fault in the lower plate. The hornblende gneiss is in general lithologically similar to though not exactly the same as some rocks in the Quinebaug Formation, and no associated quartzite or quartz-rich rocks were observed in the slice. Similar hornblendic rocks have, however, been observed in the lower plate of the fault south of this area, where they are interlayered with Plainfield quartzites and quartz schists. The hornblende gneisses in the slice are cut by biotite-quartz-feldspar gneiss indistinguishable from the Scituate Gneiss, which is commonly associated with the Plainfield Formation, but has not yet been demonstrated to occur with the Quinebaug Formation. Since the rocks of the fault slice are beneath the main Lake Char fault plane and rocks of similar lithology do occur in the Plainfield Formation elsewhere, it seems probable that these rocks are part of the lower plate units, rather than part of the Quinebaug, which so far has been observed only in the upper plate.

The rocks in the fault slice are medium- to dark-gray, fine- to very-fine-grained hornblende-quartz-feldspar gneiss and amphibolite, with or without biotite as a major or minor constituent. Epidote may also occur as a major constituent in some rocks (sample D2-274, table 2), and local layers in the rock contain as much as 75 percent epidote. The rocks adjacent to the faults on either side of the slice are strongly cataclastic, and all samples observed in the Danielson quadrangle are moderately to strongly cataclastic. In these quartz and feldspar are commonly difficult to distinguish. Feldspar appears to be mostly plagioclase, though minor potassium feldspar occurs in some rocks. The plagioclase is commonly very fine grained, untwinned and altered, and its composition is difficult to determine; in most rocks it appears to be about albite or oligoclase. Much of the epidote in rocks is the result of alteration of plagioclase. Quartz grains are moderately to strongly sutured. Hornblende grains are ragged, and in some rocks broken, and in other samples are bleached to almost colorless and are chloritized. In the large cuts along the Connecticut Turnpike just east of the Danielson quadrangle some of the hornblende gneisses and amphbolites are granoblastic gneisses which show little or no indication of cataclasis. These rocks, however, are interlayered with and grade into mylonite and blastomylonite, especially near the fault contact with the underlying quartzite.

Origin and age.--The origin and age of the Plainfield Formation cannot be readily determined in the Plainfield-Danielson area, since such a small part of the unit occurs here, and what is here has been regionally metamorphosed and cataclastically deformed subsequent to deposition. The rocks were probably deposited as clean quartz sands with interlayered dirty sands, in which the impurities were clays in some layers and calcareous sediments in others. The hornblende gneisses may have been dolostones or may have been tuffaceous volcanic rocks.

The Plainfield Formation is provisionally dated as Cambrian(?), but no direct evidence of the age has been found. Goldsmith (1966) and Lundgren (1966a) have established that the Plainfield Formation is stratigraphically older than the metavolcanic rocks of the Monson Gneiss and Middletown Formation of middle(?) Ordovician age. The Cambrian age is supported by the presence of fossil bearing quartzite cobbles in the conglomerates of the Narragansett basin of Rhode Island, and in the beach sands of southern Rhode Island and eastern Massachusetts (Shaler, Woodworth and Foerste, 1899). The quartzite of the cobbles is in general similar to the Westboro quartzite north of the Narragansett basin, which has been correlated with, and is in part continuous with the Plainfield Formation.

Table 2.--Modal analyses of the Plainfield Formation

	T2-3	P2-262	P2-172	D5-14	D2-274
Quartz	84	89	29	78	22
Plagioclase	4		15	3	37
K feldspar	1	5		7	
Biotite	2	3			1
Muscovite	4	2		x	
Hornblende			36		17
Actinolite				8	
Epidote			5	2	15
Sphene			6	0.4	5
Opaques		x	0.3	x	0.1
Apatite			0.2	x	0.2
Zircon		0.1		x	x
Calcite			0.5	1	
Alteration?1/	3		7	0.2	2
Chlorite2/	1(b)		0.4(h)		
Sericite3/	1(p)	1(p)			
Comp. of Plag	An20		An35-45		An10(?)

All percentages rounded off to the nearest whole number, except those less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.

1/ Undetermined alteration; in part apparently a mixture.

2/ Chlorite from (b) biotite, (h) hornblende.

3/ Sericite from (p) plagioclase.

Plainfield Formation:

T2-3 (T-12.4N; 14.3W): Yellowish-gray, small-grained quartzite, with thin micaceous planes of parting. Feldspar is fine-grained, mostly untwinned, and is strongly sericitized. Biotite is dark yellow orange (10YR 6/6), and is partially chloritized. Quartz grains have fairly smooth boundaries. Average grain size is about 0.7 mm (plate 7, fig. 1).

P2-262 (P-30.9N; 0.6W): Grayish-orange, fine-grained, massive, quartzite. Sample is very hard and brittle. Foliation is defined by a diffuse lamination; a stained cut surface shows streaks of fine-grained potassium feldspar parallel to the lamination. A prounounced lineation commonly has an orange stain and possibly represents micaceous streaks. Quartz grains are elongated parallel to the foliation; the ratio of length to width is about 2:1. Quartz boundaries are moderately sutured. Biotite is very pale orange, and in the very fine grains is difficult to distinguish from muscovite. Average grain size is 0.2 mm (plate 7, fig. 2).

P2-172 (P-7.7N; 9.2W): Greenish-black, fine-grained, poorly foliated plagioclase-quartz-hornblende granulite. A strong lineation is represented by white quartz-feldspar streaks and orientation of hornblende grains. The weak foliation is a diffuse lamination of alternating light and dark streaks. Quartz is moderately sutured. Hornblende is moderate yellow green (10GY 6/4), though in part it is bleached almost colorless and chloritized. The unidentified alteration appears to be mostly after plagioclase, and may be a mixture of sericite and something else. Average grain size is 0.2 mm.

D5-14 (D-29.7N; 0.3W): Light-blueish-gray, very-fine-grained quartzite. Foliation is defined by a diffuse lamination. Thin quartz bands (less than 1 mm thick) cross the lamination at a low angle. Fine-grained, very-pale-green actinolite is subhedral to euhedral. Quartz grains are moderately sutured and commonly elongate. In the quartz bands, the grains are strongly sutured, larger and more elongate (as much as 2 mm long by 1/4 mm wide) than in the rest of the rock. Average grain size (except for the quartz bands) is 0.05 mm (plate 17, fig. 4).

D2-274 (D-7.3N; 1.1W): Greenish-gray, fine- to small-grained epidote-hornblende-quartz-plagioclase gneiss. Foliation is defined by planar streaks of hornblende and plagioclase grains. Sample contains an epidote-rich layer about 1/2 inch thick, with minor hornblende, quartz and plagioclase. The layer crosses the foliation at a low angle. Plagioclase is poorly twinned and is distinguished from quartz primarily by very-fine sericitic dust; the composition is probably sodic oligoclase. Hornblende color varies from grayish green (5G 5/2) to dusky yellow green (5GY 5/2), and grain boundaries are shredded and irregular. Biotite is light olive (10Y 5/4). Epidote is partly after hornblende and plagioclase, but may be partly primary metamorphic. Quartz boundaries are weakly sutured. Average grain size is 0.1 mm.

Quinebaug Formation

The Quinebaug Formation is a unit of primarily metavolcanic rocks, with secondary amounts of interlayered metasedimentary rocks. It forms the lower half of the Putnam Gneiss of Gregory (in Rice and Gregory, 1906) and includes Foye's (1949) hornblende gneiss and amphibolite unit and limestone and dolomite unit of the Putnam Series. The Putnam Gneiss was redefined as the Putnam Group (Dixon, 1964) and separated into two formations, the lower of which was named the Quinebaug Formation for the Quinebaug River which courses through the formation from the Lake Char thrust fault at the base to the upper part.

The Quinebaug Formation can be separated into three main units. The upper and lower units are made up primarily of hornblende gneiss, biotite gneiss and amphibolite of probable volcanic origin. The middle member, named the Black Hill Member, consists of micaceous schist and gneiss of probable sedimentary origin. In the northern part of the Danielson quadrangle a felsic gneiss mostly of tonalitic composition is associated with the Black Hill Member, and apparently occurs between the Black Hill and the upper members. The Quinebaug Formation has a maximum apparent thickness of about 7,000 feet. It thins to the north as it is cut out by the Lake Char fault.

The Quinebaug Formation is bounded on the east by the Lake Char thrust fault and on the west it is overlain by the Tatnic Hill Formation. How much of the lower part of the Quinebaug has been cut out by the fault cannot be determined, as the unit has not been studied in an area where it is not faulted. The unit extends northward to the vicinity of Webster in southern Massachusetts, where it is apparently cut out entirely by the Lake Char fault; to the south it is cut off by the

Honey Hill fault (plate 6). In general the unit trends north-northeast and dips west at moderate angles, although local areas of almost vertical dips are observed in the cataclastic lower part.

Most of the Quinebaug Formation is, or prior to cataclasis was, in the sillimanite-muscovite grade of metamorphism. Rocks containing aluminum-silicate minerals are rare, but a few lenses occur in the Black Hill Member and the lower member, and in these rocks sillimanite is associated with primary metamorphic muscovite. Subsequent to regional metamorphism most of the Quinebaug was subjected to cataclastic deformation. All rocks of the lower member which were studied are cataclastic and in the Black Hill and upper members cataclastic rocks are common.

Lower Member

The lower member of the Quinebaug Formation is a complex, heterogeneous unit of mixed metavolcanic rocks and subsidiary metasedimentary and probable intrusive rocks. The intrusive rocks occur only as mylonite gneisses in the strongly cataclastic lower part of the unit. The lower member has a maximum apparent thickness of about 4,000 feet in the Plainfield quadrangle and of about 750 feet in the northern part of the Danielson quadrangle. The thickness decreases to the north as the unit is cut out by the Lake Char fault. The thickness figures are, however, very approximate as the unit commonly shows abundant small scale folds and faults. The folds, which could not be mapped out, would exaggerate the thickness, and the faults, whose displacement cannot be determined, could either exaggerate or reduce the thickness.

All rocks of the lower member are cataclastic rocks; in general the degree of cataclasis increases in intensity downward toward the Lake Char fault. Interlayered mylonite, mylonite gneiss and locally blastomylonite form a zone of rocks about 500 feet thick at the base of the unit, and rocks in this belt are so thoroughly granulated that the mineralogy of the rock cannot be recognized in hand sample. These rocks were separated on the Danielson and Plainfield maps (pl. 2 and 3) as qlc, and differ from the rest of ql only in the degree of cataclasis. They grade fairly rapidly into mylonite gneiss in which the fine- to small-grained minerals are recognizable. In the rest of the unit the rocks are mortar gneisses, mylonite gneisses and locally mylonite or blastomylonite. The probable intrusive gneisses in the mylonitic lower part of the unit were separated as qlg on the Plainfield map. These rocks are, however, in places difficult to distinguish from mylonite gneiss in qlc, and on the compilation map (pl. 6) the distinctions were not made, but qlg and qlc were combined with ql.

The rocks of the lower member of the Quinebaug are interlayered light- to dark-gray, olive-gray, and dark-greenish-gray, very-fine- to small-grained gneisses. The rocks are well layered with layers an inch to a foot or two in thickness. The layers are commonly uniform in thickness for tens of feet along strike, and the boundary between layers is sharp. Massive amphibolite or hornblende gneiss 10 to 20 feet thick was observed locally, but could not be traced beyond a given outcrop area. In most large exposures the layers are commonly folded into small, tight, isoclinal folds. The cataclastic foliation is commonly parallel to the layering. In the mylonite and mylonite gneiss in the lower part of the member, closely spaced planes of cataclastic foliation may be strongly slickensided.

Modal analyses of the more common rock types in the lower member are given in table 3. The characteristic rock of the unit, though not necessarily the most abundant, is a mottled, medium- to dark-gray, locally light-gray, hornblende gneiss with medium to coarse hornblende and plagioclase grains (table 3, samples P2-191 and P2-208). Whether it is the dominant rock of an exposure, or in thin layers, the hornblende gneiss can be found in almost every exposure of any size, except in the mylonite and mylonite gneisses in the lower part of the unit where rock types cannot be recognized. The hornblende and plagioclase are in a fine-grained, granulated matrix of quartz, plagioclase, biotite and epidote. The gneisses have a wide variation in the proportion of the constituent minerals. The major minerals are quartz (5 to 35 percent), plagioclase (5 to 50 percent), hornblende (5 to 60 percent), biotite (0 to 30 percent) and epidote (3 to 30 percent). Muscovite may be present in amounts up to 15 percent. In many rocks muscovite is gradational into sericite and is secondary after plagioclase, but in others it may be a primary metamorphic mineral. Garnet also may be present in minor amounts. Accessory minerals include sphene, allanite (commonly surrounded by epidote), apatite, opaque minerals, zircon and locally tourmaline. Potassium feldspar is also an accessory mineral in some rocks; it is associated with and probably exsolved from plagioclase.

Not all hornblende gneisses in the unit have the mottled appearance, but many are essentially granular, fine-grained gneisses, with or without coarse plagioclase grains. The mineralogy of these rocks is about the same, with the same variations, as the mottled hornblende gneiss. With a decrease in the amount of quartz, the hornblende gneiss grades into amphibolite, consisting primarily of hornblende and plagioclase and lesser amounts of biotite and epidote (table 3, samples P2-154 and PN 65). Biotite is commonly less than 5 percent in the amphibolites, but may make up as much as 20 percent of the rock. Muscovite and garnet were not observed in amphibolite. Anthophyllite was observed in one sample (table 3, P2-330); this is the only anthophyllite bearing rock found in the lower member of the Quinebaug, although anthophyllite was specifically looked for. Scapolite, probably secondary after plagioclase, occurs in some amphibolite.

Interlayered with the hornblendic rocks are a variety of rock types. The most common is light- to dark-gray biotite-quartz-plagioclase gneiss, which is probably the most abundant rock of the lower member (table 3, samples P1-164, D2-220, and P2-324). The rocks consist of plagioclase (15 to 60 percent), quartz (15 to 50 percent), biotite (5 to 35 percent) and secondary amounts of epidote (0 to 30 percent, but in most rocks less than 10 percent) and muscovite (0 to 15 percent). Garnet is more common in these rocks than in the hornblende gneisses, but rarely amounts to more than one percent. Minor amounts of microcline, less than 5 percent, may occur locally in the biotite gneiss. Lenses of muscovite-biotite gneiss containing sillimanite and garnet were noted at three widely separated localities. The sillimanitic gneisses are similar to those in the Tatnic Hill Formation, and suggest some metasedimentary rocks are interlayered with the metavolcanic rocks in the lower member of the Quinebaug. A few small lenses of calc-silicate gneiss occur locally; these consist of orange grossularitic garnet, diopside, hornblende, quartz and plagioclase. Other varieties in the lower member include rocks rich in epidote or in scapolite. The former contain 50 to 80 percent epidote and minor hornblende, quartz, chlorite or calcite. Accessory minerals in all rock varieties are in general similar to those in the hornblende gneisses, except that sphene is less common in the biotite gneiss.

In the lower part of the lower member two feldspar gneisses are intermixed with the hornblende and biotite gneisses (table 3, P2-185). These are best seen in the road cuts along the Plainfield connector to the Connecticut turnpike (P-21.6N; 9.7W) and on the east slope of the long hill north of the cuts. In places the two feldspar gneisses appear to have an intrusive relationship with the other rocks, but all rocks in this area are mylonite and mylonite gneiss, and original relationships are difficult to determine. The two feldspar gneisses are medium- to dark-gray mylonite gneisses, with porphyroclasts of pink to white microcline and white plagioclase in a very-fine-grained granulated matrix. These rocks can be distinguished megascopically from the hornblende and biotite mylonite gneisses, which also contain porphyroclasts of white plagioclase, only by the pink microcline, and where the microcline is also white, they can be distinguished only in thin section. The rocks consist of approximately equal amounts of quartz, plagioclase and microcline, although the latter is commonly slightly less abundant than quartz and plagioclase. All samples examined are so thoroughly granulated, however, that aside from the feldspar porphyroclasts it is difficult to distinguish the two feldspars and quartz. Biotite (or chlorite after biotite) commonly makes up 5 to 20 percent of the rock. Muscovite and epidote may comprise as much as 10 percent of the rock, but either or both may be secondary after feldspar. Accessory minerals include apatite, zircon, sphene, opaque minerals and minor allanite.

Blastomylonites in which most minerals are neomineralized to lower grade mineral assemblages are exposed locally adjacent to the fault planes (table 3, P2-381, P1-212). These are commonly dark-greenish-gray, very-fine-grained, dense, chloritic rocks. They are commonly thinly laminated with alternating, diffuse light and dark streaks. They consist primarily of chlorite, sericite and quartz, and secondary amounts of epidote, calcite and sphene, although epidote is a major mineral in some blastomylonites. Plagioclase is recognizable in most samples, but is filled with very-fine-grained sericite. Fine-grained muscovite occurs in some rocks, and is gradational into sericite. A minor amount of hornblende may be present in even the most strongly neomineralized hornblende gneiss. The hornblende is surrounded by chlorite of about the same color. Minor biotite may be present in some rocks, but in most it is all altered to chlorite. One sample contained about 20 percent fine-grained scapolite. The scapolite is uniaxial negative, has a low birefringence and the refractive index is a little higher than quartz; it is probably a sodium rich scapolite formed from plagioclase.

All samples of the lower member which were examined show a cataclastic fabric. Although there is a large variation in fabric, the samples illustrated in plates 14 and 15 are typical for most of the unit (sample P1-141 in plate 15, fig. 3 is from the upper member of the Quinebaug Formation, but is similar to much of the lower member). The cataclastic foliation is produced by streaks of very-fine-grained minerals which are deflected around the fine- to medium-grained porphyroclasts of feldspar, hornblende and, where present, garnet. Hornblende grains especially, and less commonly, plagioclase grains, may be ground to an ellispoidal shape, with the long axes parallel to the cataclastic foliation. In the matrix streaks of very fine-grained quartz or quartz and feldspar commonly alternate with streaks of quartz, biotite, epidote or chlorite. The mylonites are more uniformly very-fine-grained rocks, commonly with a few fine- to small-grained feldspar porphyroclasts. The blastomylonites are also a fairly uniformly very-fine-grained mixture of chlorite, sericite, epidote, and quartz, although some chlorite and calcite may form fine to small size grains.

The characteristics of the minerals in the rocks of the lower member also show a wide variation. The hornblende porphyroclasts in the mortar gneisses and some mylonite gneisses have ragged, irregular boundaries (pl. 13, fig. 1 and 2; pl. 14; pl. 15, fig. 3 and 4). The fragments of hornblende broken off from the larger grains are commonly altered to actinolite, epidote or chlorite (pl. 14, fig. 3 and 4). In more thoroughly granulated rocks, hornblende grains are very fine. Locally hornblende has recrystallized to a network of fine-grained subhedral to euhedral grains (pl. 13, fig. 3). In most of the hornblende gneiss the color of the Y direction is dark to moderate yellow green (5GY) and Z is gray blue green (10BG), dusky yellow green (5GY) or yellow green (10GY). In partially neomineralized rocks hornblende is bleached to almost colorless, and in strongly neomineralized rocks it is altered to chlorite and epidote.

Feldspar may occur both as very fine grains mixed with quartz in the matrix of the rock, or, more prominently as porphyroclasts with ragged, irregular boundaries (pl. 13, fig. 1; pl. 14, 15, and 16). In the mortar gneisses and many mylonite gneisses plagioclase grains have granulated boundaries, may have bent twin lamellae and may be zoned.

In the more strongly cataclastic mylonite gneisses the grains are broken and the fractures filled with very-fine-grained quartz and feldspar. In the mylonites most plagioclase is granulated to very-fine- or fine-grained. The composition of the plagioclase varies from labradorite to almost pure albite. In the least altered hornblende gneiss and biotite gneiss the composition is about An 40, and in amphibolite it is about An 65, and these are probably close to the composition of the plagioclase prior to cataclasis and recyrstallization. The plagioclase within one thin section may vary in composition by as much as 20 percent anorthite (An 5 to An 28 was measured in one section; An 13 to An 30 in another). A minor amount of potassium feldspar occurs as fine grains along or near the edges of plagioclase in some rocks, and apparently was exsolved from the plagioclase during recrystallization. In the two feldspar gneisses, both plagioclase and microcline commonly contain wavy exsolution lamellae of the other feldspar. Some plagioclase in these gneisses is myrmekitic, but coarse coronas of myrmekite, such as described by Lundgren in the cataclastic Canterbury Gneiss (1966a) were not observed. Plagioclase shows varying degrees of alteration from fresh to almost completely sericitized or saussuritized.

Biotite in most of the rocks forms as a very-fine-grained network either in streaks or throughout the rock. In the mortar gneisses some biotite may be slightly coarser grained, but even in these the coarser biotite occurs only in the lee of plagioclase, hornblende or garnet porphyroclasts. The color of the Z direction of the biotite is commonly a shade of olive brown (5Y), but may also be yellowish orange (10YR) or green (10GY or 5G). The green biotite can be distinguished from chlorite only by the high birefringence. Biotite is partially altered to chlorite in many rocks, and in the blastomylonites almost all biotite is altered.

Garnet occurs in fine to small, subhedral to anhedral grains. In thin section it is colorless and in hand sample it is deep red. The composition of the garnet is not known but probably it is rich in almandite. The boundaries of the garnet grains show no indications of granulation (pl. 15, fig. 1 and 2). In some rocks part of all garnet is pseudomorphed by sericite, chlorite or biotite.

Quartz is commonly uniformly very fine grained. Rocks in which quartz grains are as much as 0.1 mm in diameter are rare, and where it is this coarse it shows strong undulose extinction. The quartz is either in streaks of granular grains (pl. 15, fig. 1 and 2), or, more commonly is strongly sutured (pl. 14 and 16). The granular quartz occurs mostly in rocks which show little or no neomineralization of feldspar and mafic minerals, and in the blastomylonites all quartz is strongly sutured.

Black Hill Member

The middle part of the Quinebaug Formation is a unit of micaceous schist and quartz rich gneiss of probable sedimentary origin. The unit was named the Black Hill Member (Dixon, 1964) for exposures on the southern end of Black Hill in the Plainfield quadrangle (P-23-25N; 19-22W). Many rocks in the Black Hill Member contain calcic minerals, and the rocks are non-resistant to erosion and poorly exposed. The broad valley of the Quinebaug River south of Black Hill is suggestive of an underlying non-resistant rock. In the Jewett City quadrangle Loughlin (1912) and Sclar (1958) reported dolomite lenses in the undifferentiated Putnam Gneiss. Reconnaissance in that area indicates that the dolomite is associated with a calcic biotite schist similar to much of the Black Hill Member, and occurs between belts of hornblende gneiss equivalent to the upper and lower members of the Quinebaug. North of the Black Hill area, boulders of calcic biotite schist occur between the scattered outcrop areas, suggesting a continuity of the unit. It is possible, however, that the Black Hill Member is not as continuous as it is shown on the Danielson and Plainfield geologic maps (pl. 2 and 4), but is, instead, a series of lenses.

The apparent thickness of the Black Hill Member is probably about 1,500 feet, but neither the top nor the bottom are exposed, and the unit is strongly folded. On the east side of Black Hill the lower contact of the unit is probably just above Cedar Swamp. The lowest exposed rocks west of the swamp are hornblende gneiss and amphibolite, suggesting the contact between the lower member and the Black Hill Member is gradational. The upper contact of the unit is not exposed in the Plainfield-Danielson area, and its nature is not known.

The rocks of the Black Hill Member consist of a variety of well-layered, light- to dark-gray, fine- to small-grained micaceous or hornblendic schists and gneisses, quartz rich gneisses, and minor quartzites. Many of the rocks are calcite bearing, and the weathered surface is typically pitted with solution cavities. Layers most commonly are from less than an inch to several inches in thickness. The layering in the quartz-rich gneisses especially appears to be primary bedding and small scale graded bedding, cross bedding and channeling suggest that most of the rocks are right side up. The unit characteristically shows strong internal folding, however, and every outcrop is a series of isoclinal folds. Most of the rocks show only minor indications of cataclastic deformation, but locally they are mylonite or, more commonly, blastomylonite.

The rocks of the Black Hill Member contain various combinations of quartz, plagioclase, biotite, muscovite, hornblende, epidote and calcite, and less abundantly, garnet, sillimanite and scapolite. Modal analyses of some typical rocks are given in table 4. Probably the most common rock of the unit is a medium- to dark-gray, biotite-quartz-plagioclase granular schist with or without calcite and muscovite (table 4, P2-157). Biotite ranges from 10 to almost 50 percent of these rocks, but commonly is about 20 to 25 percent. Quartz and plagioclase have about the same range as biotite, and in most rocks are 30 to 40 percent. Calcite, epidote and muscovite each may constitute 0 to 15 percent of the rock. With an increase in the amount of quartz and feldspar in proportion to the micas, the rocks are light- to medium-gray, fine-grained gneisses, and mica rich varieties are interlayered with mica poor varieties on a small scale.

Another fairly common rock type is a medium- to dark-gray biotite-hornblende-plagioclase-quartz gneiss (table 4, PN-82). These rocks also have a wide variation in the proportion of the constituent minerals, and mafic rich and mafic poor varieties are interlayered on a fine scale. Epidote commonly makes up 2 to 10 percent of the hornblende gneiss. Calcite and muscovite were not observed. The rocks are commonly fine enough grained that hornblende and biotite are difficult to distinguish megascopically.

Less abundant interlayered rock types include muscovite schist and quartzite. The schist is a medium-gray, commonly orange stained, plagioclase-muscovite-quartz schist with or without biotite, garnet and

and less commonly sillimanite (table 4, Pl-155). The most abundant minerals are quartz (30 to 70 percent) and muscovite (25 to 35 percent). Plagioclase commonly forms less than 10 percent of the rock and biotite is from 0 to 15 percent. Garnet, where present, is less than 5 percent, and in some rocks is partially to completely pseudomorphed by chlorite, sericite and biotite. Sillimanite was observed in only one sample, and only minor unaltered sillimanite was present; the majority was altered to sericite. White, small-grained quartzite, commonly orange stained, occurs as local layers as much as a few inches thick. The rock contains about 95 percent quartz, 5 percent muscovite and minor plagioclase.

On the east side of Black Hill is a lens of light- to medium-gray, fine-grained quartz-rich gneiss. The lens has a maximum apparent thickness of about 700 feet, and can be traced along strike for about 1/2 mile. Similar rocks were not observed in outcrop elsewhere in the member, although scattered boulders of the rock occur in the Danielson quadrangle, and probably it occurs as lenses throughout the unit. The rock is primarily a muscovite-quartz granular schist with secondary amounts of plagioclase, calcite, biotite, epidote, and locally scapolite (table 4, Pl-160). Quartz makes up 50 to 75 percent of the rock and muscovite is commonly 10 to 20 percent, although in some layers muscovite is minor. Plagioclase in most rocks is less than 10 percent, but locally is as much as 20 percent. Biotite constitutes 0 to 15 percent of the rock. Calcite, epidote, and where present, scapolite are commonly 5 percent or less. Minor dark-gray hornblende gneiss and amphibolite is interlayered with the quartz gneiss.

The minerals in the Black Hill Member are mostly fine to small grained and have fairly regular smooth boundaries. The average grain size of the rocks is commonly 0.2 or 0.3 mm. Quartz grains in most rocks are a fairly uniform size, and weakly to moderately sutured; only locally is quartz strongly sutured. The composition of the plagioclase varies from An 20 to An 35, except in the strongly altered rocks where it is more sodic. Biotite is commonly light or moderate olive brown (5Y), although in some rocks it is yellow brown (10YR). Hornblende is dark yellow green (10GY 4/4) to moderate blue green (5BG 4/6). The rocks commonly show minor amounts of alteration of biotite and hornblende to chlorite, of plagioclase to sericite and of garnet to sericite, chlorite and biotite; and rocks which are granulated and cataclastically deformed are more strongly altered than those which are not. Blastomylonites occur locally, and in these most of the mafic minerals are chloritized and most of the plagioclase sericitized, so the rocks contain quartz, chlorite, sericite-muscovite, epidote and some unaltered sodic plagioclase. Garnet in the blastomylonites is also completely altered. Accessory minerals in the unit include apatite, sphene, tourmaline, opaque minerals, rutile and zircon.

Tonalitic Gneiss

In the northern half of the Danielson quadrangle (pl. 2 and 6) is a lens of light-gray felsic gneiss which is associated with the Black Hill Member. The gneiss varies somewhat in composition, but is commonly tonalitic. On the eastern side, or at the base, the gneiss is gradational into the Black Hill Member. It is probably overlain by the upper member of the Quinebaug Formation, although there are no exposures to indicate the nature of the upper contact or the overlying rock. The northern part of the lens is in fault contact with the upper member both on the east and on the west. The lens has a maximum thickness of about 1,400 feet in the thickest part.

The tonalitic gneiss is commonly a light-gray, fine-grained, thinly-laminated muscovite-quartz-plagioclase gneiss. In places the plagioclase gneiss grades into a medium-grained two feldspar gneiss with coarse splotches of biotite. Elsewhere it grades into a small-grained, biotite granular schist which is similar to some of the schist in the Black Hill Member. Minor hornblende gneiss and amphibolite are interlayered with the gneiss; these were observed only in the northern part of the unit. A thin band of quartzite, about 10 feet thick, was traced for about a mile in the middle of the unit. The lamination is produced by alternating streaks of micaceous and quartz-feldspar rich layers, and the laminae are commonly less than 0.1 inch thick. Schistosity is parallel to the lamination, although many rocks show two directions of mica orientation. Most of the rocks are mortar gneisses with streaks of granulated mineral grains parallel to both directions of mica orientation. Locally the rocks are strongly granulated and contain only a few streaks of nongranulated minerals in a fine-grained granulated matrix.

Modal analyses of the tonalitic gneiss are given in table 4. The most common rock is light-gray, fine-grained laminated biotite-muscovite-quartz-plagioclase gneiss with or without minor amounts of potassium feldspar, calcite and epidote (table 4, D3-75). Quartz and plagioclase are commonly about equal in amount and make up 25 to 50 percent of the rock each. Many rocks contain a small amount of fine-grained irregular, untwinned potassium feldspar which occurs with, and is probably exsolved from plagioclase. Locally the gneiss may contain as much as 10 percent microcline (table 4, D2-31). Muscovite is commonly more abundant than biotite but locally the rocks are biotite rich (table 4, D2-8~~2~~4) and either mica may make up as much as 20 percent of the rock. Calcite and epidote each constitute 1 or 2 percent of most rocks, although calcite is lacking in some rocks. Accessory minerals include allanite (associated with the epidote), apatite, sphene, zircon, magnetite, and locally small red garnet.

The tonalitic gneiss is commonly fine to small grained, although most is somewhat granulated and the grain size is quite variable; the average of the ungranulated grains is about 0.5 mm. Plagioclase grains may have either smooth, regular boundaries, or may be irregular. The composition of the plagioclase is An 15 to An 30, except where it is altered, in which case it is more sodic and may be zoned. Muscovite in some rocks, and possibly some of the calcite is secondary after plagioclase. Pleochroism of the biotite is from almost colorless to moderate olive brown (5Y) or grayish olive (10Y). Biotite in some rocks is partially altered to chlorite. Quartz grains also may have smooth, regular boundaries in the ungranulated part of the rock and be moderately to strongly sutured in the granulated parts.

The thin quartzite lens was observed only in the northern part of the tonalitic gneiss. The rock is white, grayish yellow weathering, fine-grained quartzite composed of about 90 percent quartz, minor muscovite and accessory albite, sphene, magnetite, and limonite. Streaks of granular quartz with an average size of about 0.3 mm alternate with thin granulated streaks of very-fine-grained quartz. Most of the muscovite and limonite is contained in the granulated streaks, and is oriented parallel to the streaks.

Upper Member

The upper member of the Quinebaug Formation is, in general, similar to the lower member except that the rocks are not so thoroughly cataclastic. The upper member overlies the Black Hill Member and underlies the Tatnic Hill Formation. The unit has an approximate apparent thickness of 750 to 2,000 feet. The variation in thickness may be original in part, but it is also in part tectonic. The contact between the upper member and the Black Hill Member is not exposed; it is in part a fault contact, and may be more extensively faulted than is shown on the Danielson and Plainfield maps (pl. 2 and 4). Only the upper 100 to 200 feet of the upper member is well exposed. These rocks form a series of east facing cliffs capped by the rusty weathering gneiss at the base of the Tatnic Hill Formation. A typical exposure is on the east side of Tatnic Hill (D-0-6N; 22.5-23W), where 120 feet of interlayered hornblende gneiss and biotite gneiss are exposed below the rusty weathering gneiss at the top of the hill. Within 10 to 20 feet of the contact the Quinebaug gneisses are also slightly iron stained.

The rocks of the upper member consist of interlayered medium- to dark-greenish-gray, fine- to medium-grained hornblende gneiss, biotite gneiss and amphibolite. The rocks are well layered; individual layers are from a few inches to a few feet thick, and commonly maintain a uniform thickness for tens of feet along strike. The layering in part probably represents primary bedding, and in the upper part of the unit most bedding top criteria indicate the rocks are right side up. In places, however, the plane of layering can be demonstrated to be a shear plane. A common feature of the upper member is small pods, a few inches to a foot in diameter, of amphibolite, epidote granulite, or diopside-scapolite-hornblende granulite. These pods commonly show evidence of rotation.

Modal analyses of samples of the upper member of the Quinebaug Formation are given in table 5. As in the lower member the characteristic rock of the unit is a mottled medium-gray, hornblende gneiss containing coarse hornblende and plagioclase grains in a fine- to small-grained matrix of hornblende, plagioclase, biotite, epidote and with or without quartz (table 5, P1-60). The coarse hornblende gneiss is not as abundant as it is in the lower member, and in some large exposures, such as the cliffs west of the Quinebaug River in the northern part of the Danielson quadrangle, the rocks are primarily interlayered equigranular hornblende gneiss and biotite gneiss. In some of the coarse hornblende gneiss of the upper member, however, the hornblende megacrysts are larger than any observed in the lower member; this may be because of less intense cataclasis in the upper member. The most abundant rock of the unit is biotite-quartz-andesine gneiss (table 5, P1-143, D3-85), although it is commonly interlayered with biotite-quartz-andesine-hornblende gneiss on a small scale (table 5, P1-141). The variations in the proportions of the constituent minerals of the rocks of the upper member are about the same as those in the lower member. Minor amounts of potassium feldspar may be present in any of the rocks, but it is more likely to occur in the biotite gneiss than in the hornblende gneiss. Epidote is a common minor constituent of most of the rocks. Muscovite may be present in either the biotite gneiss or the hornblende gneiss, but most of it appears to be secondary after plagioclase. Minor amounts of garnet may also be present in any of the rock types. Accessory minerals include opaque minerals, rutile, allanite (associated with epidote), zircon, sphene, apatite, and locally tourmaline and calcite. Calcite, where present, is also apparently an alteration of plagioclase.

Also interlayered with the rocks of the upper member is plagioclase-hornblende amphibolite, with secondary amounts of biotite, epidote and in some rocks minor diopside. The amphibolite is commonly laminated with alternating, thin plagioclase and hornblende rich layers. Local lenses may contain 95 percent actinolite and minor quartz, plagioclase and chlorite. The actinolite is grayish green in hand sample, and colorless in thin section. An unusual amphibolite is exposed in a road cut just west of the Quinebaug River in the Danielson quadrangle (D-36.ON; 13.3W). It is shown on the Danielson map (pl. 2) as part of the upper member, but there are no other outcrops nearby to indicate what type of rock it is associated with, and it could be a part of the Black Hill Member. The rock is composed of about 40 percent each hornblende and scapolite and secondary amounts of altered plagioclase, chlorite, magnetite and sphene. The scapolite is associated with and appears to be replacing plagioclase. The hornblende is color zoned with pale, bleached cores and dark-yellow-green rims. The rock apparently was partially neomineralized during cataclasis. Similar amphibolite was not observed in outcrop elsewhere in the area, but a sample of similar composition was collected from a boulder by G. Neuerberg in the Plainfield quadrangle. The source of the boulder is unknown, but it does suggest similar amphibolites may occur in the area.

Amphibolite may also occur in small pods a few inches to a foot in diameter. The amphibolite is commonly layered and the layering is at an angle to the foliation and layering in the surrounding rock, indicating rotation of the pods. Other pods in the upper member are primarily epidote with minor hornblende, quartz and plagioclase, or consist of various combinations of hornblende, diopside, scapolite, plagioclase, epidote and minor quartz, and biotite (table 5, Pl-74).

The rocks of the upper member of the Quinebaug Formation have an average grain size which varies from 0.2 to 0.7 mm; the amphibolites may be somewhat coarser with an average grain of about 1 mm. Rocks which show little or no evidence of cataclastic deformation are essentially equigranular with or without coarse plagioclase or hornblende grains, and the grains have generally smooth boundaries. Most rocks, however, show some granulation of grains especially around the edges of the coarse plagioclase and hornblende, and in these the coarse grains have ragged, irregular boundaries. Plagioclase composition in most grains is between An 30 and An 45, but locally it may be a sodic as An 20 and in the amphibolites may be as calcic as An 60. The potassium feldspar, where present, is commonly as fine grains associated with, and probably exsolved from plagioclase, although in some biotite gneiss it may form as small, discrete grains of microcline. The color of the hornblende shows some variation. In some rocks Y and Z are grayish green or dusky yellow green (10GY) and in others, especially the amphibolites, they are olive brown (5Y). The refractive indices of one of the coarse hornblende grains from Pl-60 are: $\alpha = 1.670$; $\beta = 1.688$; $\gamma = 1.693$; $2V_x = 68^\circ$. These indicate a ratio of Fe^{++}/Mg of about 60 (Tröger, 1956). The Z direction of biotite is either olive brown (5Y) or yellow brown (10YR). The color of the biotite does not appear to relate to the mineralogy of the rock for either color may occur in the biotite gneiss or in hornblende gneiss. Minor amounts of secondary minerals are present in many rocks. These include sericite-muscovite after plagioclase and less commonly after garnet, chlorite after biotite or hornblende and minor calcite after plagioclase. Some of the epidote is also secondary after plagioclase or hornblende.

Age and correlation of the Quinebaug Formation

There is no direct evidence to indicate the age of the Quinebaug Formation. It underlies, and is older than the Tatnic Hill Formation, but the age relative to the Plainfield Formation cannot be determined in this area, as the two are in fault contact. The Quinebaug is tentatively correlated with the Middletown Formation and the Monson Gneiss on the western side of eastern Connecticut (pl. 1, table 1). The Middletown Formation is correlated with the Ammonoosuc Volcanics of New Hampshire (Rodgers et al, 1959) dated as middle Ordovician by correlation with the Beauceville Formation of Quebec, which contains middle Ordovician fossils (Cady, 1960, p. 554). Thus the probable age of the Quinebaug Formation is middle Ordovician.

The Quinebaug Formation cannot be traced directly into the Middletown or Monson Formations, and the correlation is based on superposition of metavolcanic rocks beneath correlative units of metasedimentary rocks--the Brimfield Schist and the Tatnic Hill Formation. The Middletown Formation is characterized by anthophyllitic gneiss, which is interlayered with garnetiferous gneiss, biotite gneiss, and amphibolite (Lundgren, 1963). Monson gneiss is a unit of layered to massive hornblende- and biotite-plagioclase gneiss; locally the Monson contains potassium feldspar (Lundgren, 1963, 1966a; Goldsmith, 1966). Both units are considered to represent metamorphosed volcanic rocks. Anthophyllitic gneisses are rare in the Quinebaug Formation, and where present they are not at or near the top of the unit, so the direct, lithologic equivalent of the Middletown Formation is not present in the Quinebaug Formation. The Monson Gneiss is commonly more felsic than is the Quinebaug Formation, and the coarse hornblende gneiss which is characteristic of the Quinebaug has not been described in the Monson Gneiss. The Quinebaug around the Willimantic dome is also characterized by the coarse hornblende gneiss (Snyder, 1967), but in part it consists of layered felsic gneisses which resemble Monson Gneiss more than Quinebaug. Possibly the Quinebaug in the dome represents a transition between the Quinebaug lithology of the Plainfield-Danielson area and the Monson type lithology.

The correlation of the Quinebaug Formation and Monson Gneiss is substantiated, though not proven, by comparison of the chemical analyses of the two units given in table 19. Analyses 1 to 6 are of the cataclastic lower member of the Quinebaug Formation in the Plainfield-Danielson area. Analyses 7 and 9 are also Quinebaug Formation; 7 is from a slice between two branches of the Honey Hill fault in the Old Mystic quadrangle south of this area, and 9 is from the Quinebaug in the Willimantic dome in the Columbia quadrangle (Snyder, 1967). Analyses 8 and 10 are of Monson Gneiss; 8 is from the west flank of the Hunts Brook syncline south of the Honey Hill Fault in the Niantic quadrangle (Goldsmith, 1967d), and 10 is from the core of the Monson anticline in the Marlboro quadrangle. The chemical affinity of the Quinebaug and Monson is suggested in figure 4, a plot of the ratio of alkalies ($Na_2O + K_2O$):Fe ($FeO + Fe_2O_3$ +

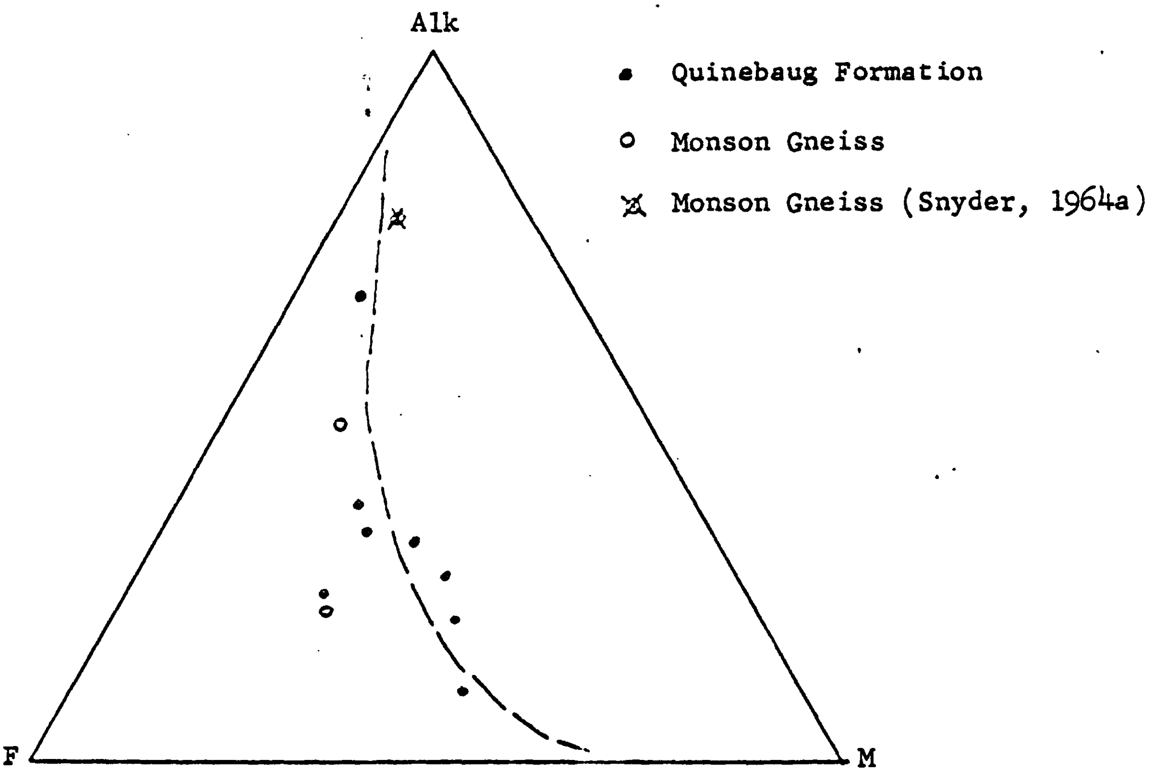


Figure 4.--Triangular diagram showing the ratios of alkali ($K_2O + Na_2O$) : F($FeO + 2Fe_2O_3 + MnO$) : M(MgO) in analysed samples of the Quinebaug Formation and Monson Gneiss.

MnO):Mg for each of the analysed samples. The ratios are concentrated along the dashed line on the diagram; this concentration is more apparent when the unpublished analyses of Monson Gneiss are also plotted.

Origin

The Quinebaug Formation apparently represents a metamorphosed sequence of primarily volcanic sediments. The well layered nature of most of the unit and the lithologic variation of the interlayered rock types suggests that volcanic ash was deposited in a basin which was also accumulating sedimentary material, which in part at least, was probably reworked volcanic debris. There is little evidence in the rocks now for extensive flows of volcanic rock. Some of the massive amphibolite may represent original flows, but these are scarce and of limited extent. Because much of the Quinebaug is probably of mixed volcanic and sedimentary origin, chemical analyses of individual samples are of little value in determining the original composition of the volcanic material. The C.I.P.W. norms of samples P2-324 and P2-154 are about comparable to the average andesite or dolerite of Nockolds (1954, tables 5 and 6), of samples P1-208 and 1871 to dacite (table 2) and C-338 to basalt (table 7). The analysis of P1-208 is, however, also comparable to that of average graywacke, as is D2-220 (Pettijohn, 1963, table 6). At least some of the rocks also were not closed systems during all of the subsequent metamorphic deformation. Sample P1-212 is a thoroughly neomineralized blastomylonite which must have had some change in composition during cataclasis. From the overall composition of the rocks of the Quinebaug, it seems probable that the original volcanic material was andesitic to basaltic in composition.

The metasedimentary rocks of the Black Hill Member apparently represent a hiatus in the volcanic activity. The sediments that comprise the unit are probably reworked volcanic material for the most part. Pelitic schists containing abundant muscovite and sillimanite were observed only near the top of the member, suggesting more thorough weathering took place late in the deposition of the sediments of the Black Hill. The tonalitic gneiss associated with the Black Hill Member in the northern part of the Danielson quadrangle was probably a felsic tuff of dacitic composition.

The two feldspar mylonite gneisses in the lower part of the lower member appear in places to have an intrusive relationship with the rest of the unit. Some of the gneisses are indistinguishable from mylonitic gneisses of the Sterling Plutonic Group, and they may be a part of the Sterling. The two feldspar gneisses may, however, contain as much as 20 percent biotite, while the rocks of the Sterling rarely contain more than 10 percent biotite. It seems more likely that the two feldspar gneisses represent intrusive rocks associated with the volcanic activity and are about the same age as the rest of the Quinebaug Formation.

Table 3.--Modal analyses of the lower member of Qui

	P1-164	P1-191	P1-208 *	D2-220 *	P2-324 *	P2-154 *
Quartz.............	46	10	30	39	14	3
Plagioclase........	34	17	23	33	48	34
Microcline.........						
Undifferentiated1/..	2				4	
Biotite............	7	14	11	10	22	19
Muscovite..........				4		
Anthophyllite......						
Hornblende.........		51	17			36
Garnet.............	0.2				1	
Epidote............	64/(p)	64/(h,p)	94/(h,p)	8	44/(p)	24/(h
Sphene.............		1	0.7	0.2		3
Opaques............	1	1	x	2	2	2
Apatite............	x	x	0.4	0.2	0.4	0.8
Zircon.............	x				x	x
Allanite...........	x				x	
Calcite............				x		
Chlorite2/.........	0.7(b)	x(b,h)	3(h,b)	3(b)	0.8(b)	0.4
Sericite3/.........	4(p)	x(p)	6(p)		3(p)	x(p)
Comp. of plag......	An32-27	An37	An35	An33	An40	An15

Percentages rounded off to the nearest whole number, except those of less than 1
0.1 percent.
*Samples of which chemical analyses are reported in table 19.
1/ Too fine grained to distinguish; in P1-164 and P2-325 is quartz and feldspar;
2/ Chlorite from (b) biotite, (h) hornblende.
3/ Sericite from (p) plagioclase; in most samples may grade into fine-grained mu
4/ Epidote in part after plagioclase (p) or hornblende (h).

Lower Member of the Quinebaug Formation:

Pl-164 (P-22.6N; 17.7W): Light-olive gray, fine-grained garnet-epidote-biotite-quartz-feldspar gneiss. A weak foliation is defined by thin lamination of feldspathic layers parallel to the alignment of the small, sparse biotite flakes. Plagioclase augen as much as 1.5 mm long and averaging 0.5 mm are in a fine-grained, granulated matrix of quartz, plagioclase, mica and epidote. Small garnet grains are unbroken and euhedral. Quartz boundaries are moderately sutured. Some plagioclase grains are zoned and complexly twinned and some are bent. Biotite is moderate olive brown (5Y 4/4). Grain size is variable. (Pl.1~~4~~5, fig. 1 and 2.)

Pl-191 (P-3.6N; 22.5W): Dark-gray, weathers olive-gray, plagioclase-hornblende gneiss. Medium to coarse hornblende and plagioclase grains as much as 7 mm long are in a fine-grained matrix. Weak foliation is defined by streaks of plagioclase grains. Plagioclase and hornblende grains which average about 0.7 mm long are in a fine-grained, granulated matrix of quartz, plagioclase, epidote, biotite and sphene and have irregular, ragged boundaries. Quartz is weakly sutured. Biotite is moderate yellow brown (10YR 5/4) and hornblende is moderate yellow green (10GY 6/4). Grain size is variable.

Pl-208 (P-22.9N; 15.9W): Medium-gray, medium-grained epidote-biotite-hornblende-quartz-plagioclase gneiss. Black hornblende laths and coarse plagioclase grains are as much as 1/2 inch long. Foliation is defined by feldspathic layers alternating with thicker hornblende rich layers. Medium to coarse hornblende and plagioclase grains are in a fine-grained granulated matrix of quartz, biotite and epidote and have irregular ragged boundaries. Quartz is strongly sutured. Some plagioclase grains are filled with sericite and less abundantly epidote and chlorite; other plagioclase is fresh and unaltered. Biotite is mostly moderate olive brown (5Y 4/4) but is variable to green. Hornblende is dark yellow green (10GY 4/4). Grain size is variable. (Sample collected from a temporary exposure in a building excavation.)

D2-220 (D-0.3N; 3.9W): Medium-gray, medium-grained epidote-biotite-quartz-plagioclase gneiss. Plagioclase grains are as much as 1/2 inch long. Foliation is defined by orientation of micas and a crude layering of plagioclase rich and mica rich bands. Streaks of mica and granulated quartz wrap around medium plagioclase grains. Some plagioclase shows bent lamellae and complex twinning; plagioclase boundaries are irregular. Quartz is strongly sutured. Sparse cubes of pyrite are less than 2 mm square. Biotite is moderate olive brown (5Y 4/4). Grain size is variable.

P2-324 (P-35.1N; 6.5W): Dark-gray, small-grained garnet-biotite-quartz-plagioclase gneiss. Rock is weakly foliated; foliation is primarily defined by orientation of fine-grained biotite flakes. Plagioclase augen average 0.5 mm in length and are in a matrix of granulated quartz, micas and epidote. Quartz boundaries are strongly sutured. Fine-grained garnet is subhedral to euhedral and is not granulated. Biotite is light olive brown (5Y 5/6). Grain size is variable.

P2-154 (P-23.2N; 8.5W): Medium-dark-gray, small-grained biotite-hornblende-plagioclase gneiss. Rock is poorly foliated. Clots of granulated quartz and feldspar occur between irregular, medium grains of plagioclase, hornblende and fine-grained biotite. Some plagioclase is zoned and complexly twinned. Sphene occurs as a mantle around opaque grains, probably magnetite. Biotite is dark yellow orange (10YR 6/6). Hornblende is grayish green (10GY 5/2). Average grain size is 0.5 mm.

P2-330 (P-32N; 8.4W): Speckled-dark-gray, medium-grained anothophyllite-plagioclase-hornblende gneiss. Foliation is defined by planar orientation of amphibole and plagioclase laths; elongate prisms of anthophyllite lie in the foliation plane. Plagioclase laths as much as 0.2 inches long give the rock a spotted appearance. Grain boundaries are partly smooth and regular, and in part grains are separated by irregular streaks of the unidentified alteration, which is probably a mixture of epidote and something else. Biotite is dark yellow orange (10YR 6/6). Hornblende is dusky yellow green (10GY 4/4). Average grain size is 0.5 mm.

P2-185 (P-43.8N; 1.8W): Spotted medium-light-gray, fine- to small-grained biotite-epidote-quartz-feldspar-mylonite gneiss. Contains moderate-orange-pink porphyroclasts of microcline as much as 1/4 inch long, many of which show Carlsbad twins, and less abundant, smaller, colorless porphyroclasts of plagioclase. The coarse feldspars are in a very-fine-grained, granulated matrix of quartz, feldspar, biotite and epidote. Foliation is defined by planar streaks of granulated feldspar and of micas. Feldspar porphyroclasts may be angular, rounded or augen shaped; the microcline is commonly angular and plagioclase either augen shaped or a rounded core in a granulated, strung out matrix. In thin section all feldspar grains have strongly granulated boundaries and are broken and the fractures filled with a very-fine-grained quartz and feldspar. The Carlsbad twin plane may also be a plane of microscopic granulation (similar to plate 16). Discontinuous veins, 0.5 mm or less wide, of chlorite and calcite cross the foliation. Quartz boundaries are strongly sutured. Grain size is variable.

PN-65A, PN-65B, P2-381 (P-43N; 0.7W): Exposure of the Lake Char fault. Sample PN-65B was collected 3 feet above the fault contact, PN-65A, one foot above, and P2-381 about an inch above the fault. All three rocks are considered to have been the same rock type prior to cataclasis; a hornblende gneiss or amphibolite, with about the composition of PN-65B. (Plate 13.)

PN-65B.--Medium-dark-gray, small-grained epidote-biotite-plagioclase-hornblende gneiss. Rock is poorly foliated; foliation is defined by a general planar arrangement of hornblende and plagioclase. Hornblende and plagioclase grains have very irregular boundaries. Most plagioclase is zoned, and some is complexly twinned. Some hornblende grains are filled with minute opaque inclusions. Sphene commonly mantles an opaque mineral, probably magnetite. Biotite is moderate olive brown (5Y 4/4). Hornblende is dusky yellow green (5GY 5/2). Grain size is variable. (Plate 13, fig. 1 and 2.)

PN-65A.--Medium-dark-gray, fine-grained, hard and dense rock. Rock is too fine grained to identify minerals in hand sample, except for thin streaks of plagioclase. Sample is streaked with diffuse, thin laminae. Fine-grained, untwinned plagioclase is difficult to distinguish from quartz, and is probably about oligoclase. Most plagioclase is dusted with a fine-grained sericitic alteration. Very-fine-grained, subhedral to euhedral hornblende is apparently almost completely recrystallized. Very-fine fractures cross the foliation and distort the grains along them. Hornblende is dusky yellow green (5GY 5/2). Average grain size is less than 01. mm. (Plate 13, fig. 3.)

P2-381.--Dark-greenish-gray, very-fine-grained, dense and brittle blastomylonite. Sample is weakly and diffusely laminated. Rock is crossed by numerous fine fractures filled with calcite and chlorite. Plagioclase grains are filled with a very-fine sericite dust. Plagioclase has been neomineralized to sericite, calcite, epidote and quartz. Hornblende has been neomineralized to epidote, chlorite and possibly some calcite. Average grain size is less than 0.1 mm. (Plate 13, fig. 4.)

P1-212 (P.-13.4N; 13.4W): Dark-greenish-gray, very-fine-grained chloritic blastomylonite. Sample is very hard and brittle, and is thinly laminated with diffuse, discontinuous white streaks, which are feldspathic in part. Hornblende is almost completely neomineralized to chlorite and plagioclase to sericite. Quartz has an average grain size of about 0.1 mm and is moderately sutured.

Table 4.--Modal analyses of the Black Hill Member and the tonalitic gneiss of the Quinebaug Formation

	Black Hill Member							Tonalitic Gneiss		
Sample	P1-160	PN-82 Total Sample	PN-82 (a)	PN-82 (b)	PN-82 (c)	P1-157	P1-155	D3-75	D2-31	D2-84
Quartz.............	60	44	75	58	6	19	35	39	36	31
Plagioclase........	6	26	15	26	33	24	8	34	26	40
Potassium feldspar.									19 5/	4 5/
Biotite............	4	9	2	10	13	43	11	2	1	16
Muscovite..........	22					x	31	21	14	7
Hornblende.........		11	4	1	30					
Epidote............	1	3	0.5	1	7	1	1	1 3/	0.8 3/	0.8 3/
Garnet.............							2	x		
Sphene.............	x	1	0.2	0.2	2	x		1	0.6	0.8
Zircon.............		x		x	x	x		x	x	0.1
Apatite............		0.1	x	x	0.3	1	1	x	0.1	0.3
Calcite............	4					9		2	2	0.3
Opaque minerals....	2	3	2	2	5	3	2	x 4/	0.3 4/	
Tourmaline.........	0.1	x		x						
Chlorite 1/.........	0.1(b)	2	1	1(b)	3(b,h)	0.1(b)	8(b,g)			
Sericite 2/.........		x			0.1(p)	0.2(p)	1(g)			
Plag. comp.........	An30	An25				An25	An33	An10(?)	An20	An17

Percentages rounded off to the nearest whole number, except those less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.

1/ Sericite after (p) plagioclase, (g) garnet.

2/ Chlorite after (b) biotite, (h) hornblende, (g) garnet.

3/ Epidote commonly with small allanite grains.

4/ Opaque is primarily magnetite.

5/ Potassium feldspar probably exsolved from plagioclase; in D2-31, 10 percent is microcline and 9 percent is exsolved.

Black Hill Member of the Quinebaug Formation:

Pl-160 (P-23.6N; 20.1W): Medium-light-gray, fine-grained calcite-biotite-muscovite-quartz granular schist. Weak foliation is defined by orientation of muscovite flakes, and by streaks of biotite. Weathered surface is pocked by calcite solution cavities. Quartz grains are fairly even grained with an average size of 0.2 mm, and with moderately sutured boundaries. Biotite is light olive (10Y 5/4). Average grain size is 0.2 mm.

PN-82 (P-25.6N; 21.8W): Layered, medium-light-gray to medium-dark-gray, fine-grained biotite-feldspar-quartz gneiss (b), and quartz-biotite-feldspar-hornblende schist (c). Sample contains a thin vein quartz about 0.2 inch thick with a streak of hornblende grains (a). Layers are about 1/2 inch thick and the boundary between them is sharp. Fine fractures, with granulation of grains along, or, where closely spaced, between them cross the sample, some at an angle to the foliation and some parallel to it. Foliation is defined by orientation of the micas parallel to the layering. Quartz is weakly to moderately sutured. Biotite is moderate olive brown (5Y 4/4). Hornblende is Y, dark yellow green (10GY 4/4) and Z, moderate blue green (5BG 4/6). Average grain size is 0.2 mm.

Pl-157 (P-25.2N; 22.1W): Medium-dark-gray, medium-grained calcite-quartz plagioclase-biotite schist. Granular aggregates of calcite grains form clots as much as 1/2 inch long and 0.2 inch thick. The main foliation is defined by a planar orientation of most of the biotite flakes parallel to an indistinct layering. About 20 percent of the biotite, all of the chlorite and streaks of calcite are oriented in another direction at a high angle to the more prominent foliation.

Quartz grains are moderately sutured. Biotite is grayish olive (10Y 4/2). The average grain size is 0.2 mm, but some calcite grains are as much as 1 mm diameter.

P1-155 (P-25.5N; 22.2W): Medium-gray, stained light-brown, small-grained, garnet-biotite-plagioclase-muscovite-quartz schist. Foliation is defined by planar orientation of the micas. Garnet grains are commonly about 0.5 mm diameter, but may be as much as 3 mm; garnet is strongly psuedomorphed by chlorite, sericite and biotite. Biotite is moderate yellow brown (10YR 5/4); a small percent of the biotite is secondary after garnet, but this is the same color as the rest of the biotite. Quartz is weakly sutured. Average grain size is about 0.4 mm.

Quinebaug Tonalitic Gneiss:

D3-75 (D-33.2N; 11.1W): Medium-light-gray, fine-grained, laminated muscovite-quartz-feldspar gneiss. The laminae are from very thin to 0.2 inch thick and as much as 2 inches long, and are segregations of micas, quartz and felspar. Mica plates are principally oriented in the lamination plane, but are also in a weak second plane. Plagioclase is altered and most grains are filled with muscovite. Sample contains a few skeletal anhedral garnet grains. Quartz grains are moderately sutured. Biotite is moderate olive brown (5Y 4/4). Average grain size is about 0.1 mm, though the grains are variable in size.

D2-31 (D-36.2N; 12.4W): Light-gray, small-grained, muscovite-quartz-feldspar gneiss. Foliation is marked by planes of concentration of muscovite flakes and of streaked out feldspar. About half the potassium feldspar is microcline and the other half is in small irregular grains adjacent to and exsolved from plagioclase. Muscovite flakes are poikilitic; the inclusions are probably quartz. Quartz is moderately sutured. Biotite is grayish olive (10Y 4/2). Granulated streaks of quartz and feldspar parallel the foliation. Average grain size between the granulated streaks is 0.3 mm.

D2-84 (D-34.8N; 11.1W): Medium-dark-gray, fine-grained muscovite-biotite-quartz-feldspar gneiss. The rock shows two foliation planes; a flat lying plane of mica schistosity controls the splitting of the rock, and the second plane, at an angle of about 30° to the first, is marked both by micas and by streaked out quartz and feldspars. Granulation occurs along both planes. A rod-like, splintery lineation is at the intersection of the two planes. Potassium feldspar is in fine, irregular grains adjacent to plagioclase, and is apparently exsolved from plagioclase. Plagioclase grains have irregular boundaries. Quartz is weakly sutured. Biotite is moderate olive brown (5Y 4/4). Average grain size is 02. mm.

Table 5.--Modal analyses of the upper member of the Quinebaug Formation

	P1-143	D3-85	P1-141	P1-60	P1-74
Quartz	25	24	11	2 5/	1
Plagioclase	59	38	35	53	14
Potassium feldspar	3	1		1 5/	
Biotite	7	27	3	24	1
Muscovite		5 4/		2 4/	
Hornblende			41	10	8
Actinolite					2
Diopside					44
Scapolite					21
Epidote	0.7 3/	3 3/	1	6	6
Apatite	0.4	0.2	x	1	1
Sphene	1	2	0.5	x	0.7
Garnet				x	
Opaque minerals	2	0.2	0.7	1	
Zircon	x	x		0.2	
Tourmaline		0.1			
Calcite					x
Limonite				0.8	
Chlorite 1/	1(b)	x(b)	6(h)		
Sericite 2/	x(p)	x(p)	1(p)		
Plag. comp.	An25	An30	An40-45	An45	An60

Percentages rounded off to the nearest whole number, except those of less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.

1/ Chlorite from (h) hornblende, (b) biotite.

2/ Sericite from (p) plagioclase.

3/ Epidote may be associated with allanite.

4/ Muscovite secondary after plagioclase and biotite.

5/ Quartz and potassium feldspar mostly in a small dike less than 0.1 mm wide.

Upper member of the Quinebaug Formation:

P1-143 (P-36.6N; 22.6W): Laminated, pinkish-gray, light-gray and medium-dark-gray, fine-grained, biotite-quartz-feldspar gneiss. The lamination represents variations in the amount of biotite; fine-grained biotite is oriented parallel to the lamination. Medium to coarse plagioclase and, less abundant microcline are commonly surrounded by a shell of granulated quartz and feldspar. The thin section shows streaks of granulated grains, parallel to the biotite orientation. Most quartz is granular, but in the granulated streaks it is moderately sutured. Some of the plagioclase grains are zoned, especially near the granulated streaks. Biotite is greenish olive (10YR 4/2). Average grain size is about 0.2 mm.

D3-85 (D-37.6N; 15.2W): Medium-gray, fine-grained, layered biotite-quartz-feldspar gneiss and epidote-hornblende-biotite-quartz-feldspar gneiss. The biotite-quartz-feldspar layer is 1 1/2 inches thick and bounded on either side by hornblende gneiss, which is similar to P1-60, but was not included in the thin section. Fine scale internal banding in both rock types is parallel to the layering. Some bands are thin (1/10 inch), white quartz-feldspar bands, some of which connect coarse plagioclase grains and others are deflected around the plagioclase grains. Other bands (as much as 1/4 inch) are biotite rich. Megacrysts of plagioclase are as much as 1/2 inch diameter; some are granulated around the edges and drawn out to augen shape and others are rounded. In thin section the white bands are very-fine-grained, granulated quartz and plagioclase and may contain small to medium size, rounded plagioclase. The coarse plagioclase grains are surrounded by a shell of granulated minerals, have irregular boundaries, some are broken and the fracturesfilled with quartz, and some are zoned. Mica orientation is parallel to the granulated bands, and both may be deflected by the plagioclase megacrysts. Quartz is strongly sutured in the granulated bands; elsewhere it is weakly sutured. Biotite is moderate yellow brown (10YR 5/4). Grain size is variable, but in the least granulated matrix it averages 0.3 mm.

Pl-141 (P-37.6N; 22.7W): Medium-dark-gray, medium-grained, biotite-quartz-plagioclase-hornblende gneiss. Foliation is defined by planar arrangement of hornblende and plagioclase streaks. Several small fractures cross the foliation. Along the fractures is a zone as much as 0.5 mm wide of strong granulation in which the very-fine-grained quartz is strongly sutured, plagioclase is fractured and sericitized and hornblende is chloritized. The rest of the rock is a mortar gneiss in which granulation is seen mostly around the boundaries of the medium-sized hornblende and plagioclase grains. Quartz boundaries are granular in part and moderately sutured in the granulated areas. Biotite is moderate yellow brown (10YR 5/4). Hornblende is dusky yellow green (5GY 5/2). Grain size is variable. (Plate 15, fig. 3).

Pl-60 (P-5.1N; 32.2W): Olive-gray, fine- to medium-grained garnet-quartz-biotite-hornblende-plagioclase gneiss. The rock is spotted with grains of hornblende as much as 1/2 inch long, with plagioclase grains of about the same order of size, and with clots of smaller plagioclase grains. Bands of granulated quartz and feldspar may surround and connect some of the coarse plagioclase grains. Foliation is defined by a layering in which hornblende rich rock alternates with biotite rich rock. The layering is parallel to the plane of schistosity. Small garnet grains stand out on the weathered foliation surface, although none were included in the thin section. The coarse hornblende and plagioclase grains in thin section are surrounded by fine-grained granulated plagioclase and biotite. Biotite is light brown (5YR 5/6). Hornblende is dusky yellow green (5GY 5/2). Grain size is variable.

Pl-74 (P-0.2N; 30.3W): Dark-greenish-gray, medium-grained, biotite-epidote-hornblende-scapolite-plagioclase-diopside granulite. Scapolite and plagioclase cannot be distinguished megascopically; scapolite commonly surrounds plagioclase and apparently is an alteration of plagioclase. Much of the epidote is secondary after hornblende. Biotite is light brown (5YR 5/6). Hornblende is pale yellowish green (10GY 7/2). Diopside is dusky yellow green megascopically and is colorless in thin section. The average grain size is 0.8 mm. Sample is from a small pod, about 3 inches in diameter in hornblende gneiss.

Tatnic Hill Formation

The Tatnic Hill Formation overlies the Quinebaug Formation in apparent conformity. It forms the upper part of the Putnam Group, or the western half of the Putnam Gneiss of Gregory (in Rice and Gregory, 1906). The unit was named (Dixon, 1964) for exposures on and west of Tatnic Hill in the southwestern corner of the Danielson quadrangle. The formation consists of a series of micaceous schists and gneisses and less abundant calc-silicate gneisses and amphibolites of sedimentary origin, although some of the amphibolites near the base of the unit may have been originally volcanic rocks. In the Plainfield-Danielson area, the Tatnic Hill Formation extends through the center of the area from the southern edge of the Scotland quadrangle to the northern edge of the Danielson quadrangle. A small area of Tatnic Hill is also mapped on the western edge of the Hampton quadrangle, where the unit is on the east flank of the Willimantic dome (see pl. 1; fig. 2). On earlier maps that part of the Tatnic Hill of the Willimantic dome was included with the Eastford Gneiss (Rice and Gregory, 1906; Foye, 1949; Rodgers et al, 1956).

The Tatnic Hill Formation is divided into three main members, and the lower member is further subdivided into several lithologic units. The major subdivision of the formation was made by Snyder (1961) in the Norwich quadrangle, where the Putnam Gneiss is equivalent to the Tatnic Hill Formation, and his breakdown of the unit is followed here, though with some modification (see Dixon, 1964). The lower member and the upper one, the Yantic Member, are micaceous gneisses and schists of varying composition, with minor interlayered calc-silicate gneiss and amphibolite. The middle member, the Fly Pond Member (Snyder, 1961) consists of thinly-layered calc-silicate gneiss.

The rocks of the Tatnic Hill Formation trend northeast and dip northwest at a moderate angle, commonly less than 35°. The unit is underlain by the Quinebaug Formation on the east and overlain by the Hebron Formation on the west. It extends south of the Plainfield-Danielson area to the Honey Hill fault, and the lower part is cut out by the fault. The upper part of the unit can be traced southwest as a narrow belt above the fault into the Chester syncline (pl. 1). North of the Plainfield-Danielson area the unit can be traced continuously into southern Massachusetts. The Tatnic Hill has a maximum apparent thickness of about 5,500 feet in the southern part of the Plainfield-Danielson area, and of about 2,000 feet in the northern part. The northward thinning of the unit is apparent from the southern part of the Norwich quadrangle (Snyder, 1961) into the Putnam quadrangle. Preliminary mapping in the Putnam area suggests the unit is thinnest near the village of Putnam, and increases in thickness again north of the village. All units of the formation are affected by the northward thinning, except for the Yantic Member at the top, which retains a fairly uniform thickness across the area.

The rocks of the Tatnic Hill Formation are in the staurolite-kyanite, sillimanite and sillimanite-potassium feldspar grades of metamorphism. Rocks in staurolite-kyanite grade occur only in the upper part of the Yantic Member. The rest of the Yantic Member, the Fly Pond Member and the upper part of the lower member are sillimanite grade rocks, and those in the lower half of the lower member near the base of the unit are sillimanite-potassium feldspar grade. Muscovite occurs in many of the sillimanite-potassium feldspar grade rocks; in some rocks it is probably a primary metamorphic mineral, but in others it is a secondary mineral.

Hypersthene bearing rocks and kyanite bearing rocks are locally interlayered with the sillimanite-potassium feldspar grade gneisses, but cordierite, which was reported by Snyder (1961) in the highest grade rocks in the Norwich quadrangle, was not observed. Many rocks in the lower member were cataclastically deformed subsequent to regional metamorphism. Cataclasis is most common and strongest in the eastern, or lower part of the unit and decreases to the west.

Lower Member

The lower member of the Tatnic Hill Formation is made up primarily of various micaceous gneisses with minor interlayered calc-silicate gneisses and amphibolites. The member has been subdivided into several lithologic units which, from bottom to top are designated as the rusty weathering gneiss (tr), biotite-garnet gneiss (tb), sillimanite gneiss (ts), and biotite-muscovite gneiss (tbm). A lens of clac-silicate gneiss (tc) was traced for about 5 miles along strike in the Plainfield quadrangle, and a smaller one in the Danielson quadrangle. Other lenses of calc-silicate gneiss occur in the lower member, but could not be traced beyond a given outcrop. Amphibolite lenses occur throughout the member, and increase in abundance toward the base. These lithologic units are in general continuous with and equivalent to the several lithologic units below the Fly Pond Member in the Putnam Gneiss of the Norwich quadrangle (Snyder, 1961). In that area Snyder (1961) mapped lenses of a hornblende gneiss, called the Bates Pond Lentil, at about the stratigraphic position of the garnet-biotite gneiss. He describes the rock as a uniform unlayered gray gneiss containing large porphyroclasts of black hornblende and flesh colored soda-orthoclase. This rock was not observed in the Plainfield-Danielson area, although a few small lenses of a medium-gray, medium-grained hornblende gneiss, without coarse feldspar or hornblende are interlayered with the garnet-biotite-gneiss.

The contact between the lower member of the Tatnic Hill Formation and the upper member of the Quinebaug Formation is sharp and apparently conformable. The contact is well exposed in several places, commonly near the top of the east facing hills and cliffs of the upper member of the Quinebaug Formation. Locally the contact is along a fault, but elsewhere it appears to be a normal, conformable contact. The rusty weathering gneiss marks the base of the Tatnic Hill Formation; it is commonly 75 to 150 feet in thickness and contains abundant interlayered amphibolite lenses. Near the village of Canterbury (P-26.6N; 26.4W) the unit is considerably wider than it is elsewhere, but the rocks are strongly cataclastic and a number of small faults and folds can be observed in outcrop, so that the actual thickness there may not be much greater than it is elsewhere. The rusty weathering gneiss grades upward into the garnet-biotite gneiss, which is 150 to 500 feet in thickness. Not all the rocks in this unit contain abundant garnet, but many do, and similar highly garnetiferous rocks are rare elsewhere in the Tatnic Hill Formation; even pegmatites in this zone are abnormally rich in garnet. The garnet-biotite gneiss is overlain by the sillimanite gneiss, which has an apparent thickness of 800 to 3,000 feet, and which makes up the bulk of the lower member. The sillimanite gneiss commonly contains some garnet in small grains, but it is rarely abundant. In the Scotland quadrangle (pl. 5) and southward in the Norwich quadrangle (Snyder, 1961) the top of the lower member is the biotite-muscovite gneiss, containing no sillimanite and minor garnet. This unit has a maximum apparent thickness of about 1,000 feet and apparently it lenses out in the Plainfield quadrangle (pl. 4). The various micaceous gneisses are gradational into each other and, especially near the contact between the units, may be locally interlayered with each other. The mappable lens of calc-silicate gneiss has a maximum thickness of about 300 feet. The total thickness of the lower member in the Plainfield-Danielson area is about 4,000 feet in the south and about 1,000 feet in the north, and the northward thinning is reflected in all units.

Rusty weathering gneiss (tr on pl. 2, 4 and 6): The base of the Tatnic Hill Formation is characteristically a strongly rusty weathering gneiss. Lenses of interlayered amphibolite are abundant, and make up about 25 percent of the unit. Lenses and clots of light-gray, quartz-feldspar gneiss are also common, and probably are pegmatitic, but most of them are cataclastic and their original nature is difficult to determine. The rusty weathering gneiss may occur within the lower member as well as at the contact with the Quinebaug Formation, and is underlain by either the garnet-biotite gneiss or sillimanite gneiss. This is most common in the Danielson quadrangle (pl. 2), and in most places this repetition of lithology is interpreted to be the result of thrust faulting in the lower member rather than interlayering of lithologies. The rusty weathering gneiss is equivalent to Snyder's (1961) graphite schist phase of the Putnam Gneiss in the Norwich quadrangle.

The common rock of the rusty weathering gneiss unit is a grayish-orange, pinkish-gray, to medium-gray, small- to fine-grained biotite-plagioclase-quartz gneiss, commonly with sillimanite and garnet, and small graphite flakes. Fresh rock is medium-dark-gray but is rarely seen. In 1962 Connecticut Route 14 through Canterbury village (P-26.7N; 27-28W) was widened and new cuts made in the rusty weathering gneiss there.

Within a year the medium-dark-gray gneiss of the fresh cuts was stained grayish orange. Small, moderate-red garnet, sillimanite and sericite after sillimanite, and locally kyanite stand out on the weathered surface. Megacrysts of plagioclase are present in many rocks. Much of the rusty weathering gneiss exposed in the Plainfield-Danielson area is cataclastic, and many rocks are mylonite or blastomylonite. Near the village of Canterbury some of the mylonite gneiss resembles a conglomerate and contains porphyroclasts of quartz and feldspar, possibly of pegmatitic origin, in a fine-grained, granulated matrix.

Modal analyses of samples of the rusty weathering gneiss are given in table 6. The most common rock of the unit is a small- to very-fine-grained biotite-quartz-plagioclase gneiss with secondary amounts of sillimanite, garnet and graphite (table 6, Pl-62). Quartz commonly makes up 20 to 50 percent of the rock, plagioclase 5 to 40 percent and biotite 5 to 20 percent. In most rocks sillimanite and garnet are less than 5 percent, although sillimanite is commonly sericitized, and in some rocks may have been more abundant originally. Garnet also may be abundant locally. Some rocks contain kyanite, either with or without associated sillimanite, and it also may be abundant locally (table 6, D3-90). Many rocks contain some muscovite, but in most it is gradational into sericite and is a secondary mineral. In some rocks, however, muscovite may be a primary metamorphic mineral; in Pl-62 muscovite forms coarse plates which do not appear to be secondary. The blastomylonitic gneiss contains abundant sericite-muscovite after plagioclase, sillimanite and garnet, and chlorite after biotite and garnet (table 6, Pl-107). In the most strongly altered rocks sericite may constitute as much as 75 percent of the rock. Limonite is also a common secondary mineral, and is the cause of the rusty stain.

The fabric of the rocks shows considerable variation probably because of the varying degrees of cataclasis. In the least cataclastic rocks quartz and feldspar have an average grain size of 0.3 to 0.5 mm, although megacrysts of plagioclase as much as 10 mm diameter are common. Even these rocks, however, commonly show discontinuous streaks of granulated quartz and feldspar, and granulation around the coarse plagioclase grains. Plagioclase composition is An 30 to 35 in the least altered rocks, and more sodic in rocks in which it is altered. The fine to small quartz grains commonly show undulose extinction and moderately sutured boundaries. In the mylonite gneisses and blastomylonites quartz may be strongly sutured. Garnet may be in fresh, euhedral grains, or may be completely pseudomorphed by sericite, chlorite and biotite. Biotite is commonly light brown (5YR) or locally moderate reddish brown (10R), and commonly contains rutile needles.

Garnet-biotite gneiss (tb on pl. 2, 4, and 6): The rusty weathering gneiss grades upward into a nonrusty dark-gray to medium-dark-gray, small-grained biotite gneiss which typically contains fairly abundant garnet. The gneiss is commonly weakly layered and massive. Foliation of the non-cataclastic varities is primarily a biotite schistosity. Mortar gneiss, mylonite gneiss and locally mylonite are common within the unit, and the cataclastic rocks commonly show a moderate to strong lamination produced by stringing out of the constituent minerals during granulation. Plagioclase megacrysts are common in the rocks. Characteristic of the unit, however, are megacrysts of a pale-pink, clear orthoclase which may be an inch or more in diameter. The orthoclase has not been observed in any of the other rock types of the area, except locally in the rusty weathering gneiss and the sillimanite gneiss near the contact with the garnet-biotite gneiss. The garnet-biotite gneiss is equivalent to Snyder's (1961) biotite gneiss phase in the Norwich quadrangle, but as a stratgraphic unit rather than strictly a lithologic unit, it includes some of his sillimanite-pinite schist phase.

Modal analyses of the biotite-garnet gneiss are given in table 6. The most common rocks of the unit are a garnet-biotite-plagioclase-quartz gneiss (table 6, P1-81, D2-353 and D2-413) and biotite-plagioclase-quartz gneiss (table 6, P1-45 and P1-98) with or without potassium feldspar. Quartz is commonly more abundant than plagioclase, although locally the rock may be quartz poor (table 6, P1-135). The amount of quartz in most rocks ranges from 20 to 60 percent and is commonly about 40 percent; plagioclase ranges from 5 to 45 percent and is commonly about 30 percent; and biotite ranges from 5 to 30 percent and is commonly about 15 percent. About half of the samples examined contain 5 to 30 percent potassium feldspar, and over half of them contain 5 to 30 percent garnet. Sillimanite may constitute as much as 10 percent of the same rocks; it occurs as a rule in rocks which contain both garnet and potassium feldspar (table 6, P1-81 and D2-353). Fresh, unaltered rocks contain minor or, more commonly, no muscovite. Minor amounts of kyanite, of hornblende, or of hypersthene (table 6, P1-98) are present locally. Accessory minerals in the garnet-biotite gneiss include opaque minerals, rutile, apatite, zircon and rarely epidote.

Lenses of calc-silicate gneiss, pyroxene gneiss, hornblende gneiss, and amphibolite are interlayered with the biotite gneiss. The calc-silicate gneisses are in general similar to the larger lenses of calc-silicate gneiss in the lower member which are described later. The pyroxene gneiss is a medium-gray, small-grained rock consisting of varying amounts of diopside, plagioclase, biotite, quartz and locally scapolite and epidote, and may contain minor hornblende. These rocks are probably equivalent to the mafic calc-silicate rock of the Norwich quadrangle (Snyder, 1961). Examples of the pyroxene gneiss can be seen on the top of Tatnic Hill in the Danielson quadrangle (D-6.5N; 26.3W). Lenses of hornblende gneiss were observed at only two, widely separated localities, and were not studied in thin section. The rock is an unlayered, massive, medium-dark-gray, medium-grained biotite-hornblende-quartz-plagioclase gneiss. Other lenses within the unit are quartz-garnet granulite or biotite-garnet gneiss containing more than 50 percent garnet.

Noncataclastic varieties of the garnet-biotite gneiss are commonly small-grained, granular rocks. The minerals have an average grain size of about 0.5 mm, and have smooth, angular boundaries. Most rocks, however, show at least minor granulation around the edges of the coarse feldspar grains and small, discontinuous streaks of granulated quartz, feldspar and biotite. Examples typical of the textures of the noncataclastic gneiss, mortar gneiss and mylonite are shown in plates 9, 10, and 11. Quartz grains vary from small grained and angular to very fine grained and angular or sutured and in some ctatclastic rocks quartz grains may be elongated. Undulose extinction is common in fine- to small-grained quartz. Feldspar grains are both as average size grains and as coarse megacrysts. Plagioclase composition is commonly from An 30 to An 40, but in some cataclastic rocks plagioclase may be zoned with a more sodic outer zone. Potassium feldspar in most rocks shows microcline twinning, but in some it is untwinned. The coarse pale-pink megacrysts common in the garnet-biotite gneiss are not twinned, and are apparently orthoclase.

They commonly contain very-fine bleb-shaped inclusions of an unidentified mineral which may be quartz, or could be exsolved plagioclase; some also contain inclusions of sillimanite. Garnet is moderate-red megascopically and colorless microscopically. It is commonly euhedral and about 0.5 mm in diameter, but locally is coarse. Rocks which have been altered commonly contain black spots which represent garnet altered to chlorite and biotite. Sillimanite is commonly in fresh, individual, prismatic grains rather than the sericitized clots of needles typical of the overlying sillimanite gneiss unit. The Z direction of biotite is dark yellow brown (10YR), moderate brown (5YR), or less commonly olive brown (5Y). Secondary minerals include sericite after plagioclase, sillimanite and garnet, chlorite after biotite and garnet and minor epidote and calcite after plagioclase. Alteration is commonly minor except in some moderate to strongly cataclastic rocks.

Sillimanite gneiss (ts on pl. 2, 4, 5, and 6): The bulk of the lower member of the Tatnic Hill Formation is a medium-dark-gray, small-grained, interlayered sillimanitic mica-oligoclase-quartz gneiss and nonsillimanitic gneiss. The characteristic rock of the unit weathers to a dark-greenish-gray, and the weathered surface shows light- to dark-greenish-gray clots or thin lenses of sericite after sillimanite. The clots are commonly about 1/4 inch wide and as much as an inch long; the lenses are 0.1 inch or less in thickness and several inches in lateral extent. In both the outlines of matted sillimanite needles can be seen. Some rocks are slightly to moderately rusty weathering, but most of them are nonrusty. Small, red garnet grains also commonly stand out on the weathered surface. The rocks are commonly layered. A small scale banding consists of alternating sillimanite-sericite rich and sillimanite poor layers, commonly less than an inch thick. On a larger scale layers are 1 to 2 feet in thickness and consist of alternating sillimanitic gneiss (which shows the small scale layering) and nonsillimanitic gneiss. Boundaries between layers, both large and small scale, are sharp and only rarely suggest gradation. A schistosity formed by planar orientation of the mica flakes and of flattened quartz and feldspar lenses is commonly parallel to the layering. The sillimanite gneiss unit is equivalent to Snyder's (1961) sillimanite-pinite schist phase, but would also include some of his biotite gneiss and biotite-muscovite schist phases.

Modal analyses of the sillimanite gneiss unit are given in table 7. The common rock of the unit is a muscovite-biotite-plagioclase-quartz gneiss with or without sillimanite and garnet, and locally with potassium feldspar. The amount of quartz ranges from 25 to 60 percent and is commonly about 45 percent; plagioclase ranges from 10 to 40 percent and is commonly about 25 percent; biotite ranges from 5 to 30 percent and is commonly about 15 percent; and muscovite ranges from 0 to 20 percent and is commonly less than 10 percent. Sillimanite and garnet each are less than 5 percent in most rocks, but either one may be as much as 20 percent; sillimanite is sericitized to varying degrees, and was more abundant in some rocks prior to alteration. Kyanite may occur locally in minor amounts (table 7, P1-49). Potassium feldspar is more common in the rocks on the eastern side of the unit, and where present is commonly less than 10 percent (table 7, S7-45, S7-145), though may constitute as much as 30 percent of the rock. Accessory minerals include opaque minerals, zircon, apatite, monazite, and locally tourmaline. Epidote also occurs in accessory amounts in some rocks, but in most it is apparently secondary after plagioclase.

The rocks of the sillimanite gneiss are commonly small grained and granular. In the noncataclastic varieties grains have an average size of 0.5 to 1 mm, and have smooth, angular boundaries. In many of the rocks quartz shows moderately strong undulose extinction and weak to moderate suturing of grain boundaries. Streaks of granulated quartz, biotite and plagioclase are common in many rocks, and locally the rocks are mortar gneiss to mylonite (pl. 10 fig. 3 and 4). Cataclastic deformation in the rocks is not as common as in the garnet-biotite gneiss unit, and decreases in abundance and intensity to the west. Plagioclase is commonly in smoothly bounded grains of average size as well as in coarse grains several millimeters in diameter. The composition of the plagioclase ranges from An 25 to An 35. In some rocks plagioclase is strongly sericitized, and much of the epidote of the rocks is probably secondary after plagioclase. Potassium feldspar is commonly microcline; it may occur either as small, irregular grains, or locally as coarse megacrysts. Fresh sillimanite is commonly in fine needles, but in many rocks sillimanite is strongly altered and occurs within clots and lenses of sericite. Moderate-red garnet is most commonly in small grains a millimeter or less in diameter; in a few rocks the garnet is in elongate grains several millimeters long. Garnet is commonly fresh but may be partially altered to chlorite, sericite and biotite. Biotite is in small flakes 0.5 to 1 mm long in most of the rocks, but may be granulated to fine or very fine grained in the cataclastic rocks. The biotite of the sillimanite gneiss shows a greater variation in color than that of any other unit. In about half the samples studied, the Z direction is some shade of brown (5YR) or yellow brown (10YR) and in the other half a shade of olive brown (5Y). The biotite color is consistent within most thin sections, but in some it varies from brown to olive brown within the sample. Biotite commonly shows at least minor alteration to chlorite, but the color differences do not appear to relate to the alteration. Muscovite is a primary metamorphic mineral in some rocks and a secondary mineral in others, and both in many. In many of the rocks some muscovite has irregular boundaries that fade out into sericite, and it probably is recrystallized sericite. Sericite and chlorite are present in most rocks in amounts less than 5 percent each, but in strongly altered rocks sericite may make up as much as 50 percent and chlorite as much as 20 percent of the rock.

Biotite-muscovite gneiss (tbm on pl. 4, 5, and 6): A lens of non-rusty dark-gray, small-grained muscovite-biotite-plagioclase-quartz gneiss and schist occurs at the top of the lower member in the Scotland quadrangle and southward into the Norwich quadrangle, where the unit is equivalent to the eastern belt of the biotite-muscovite schist phase (Snyder, 1961). The unit apparently lenses out in the Plainfield quadrangle. Foliation is primarily a schistosity formed by planar arrangement of mica plates, and is parallel to a weak compositional layering with mica rich layers alternating with mica poor layers. Megacrysts of plagioclase, and close to pegmatites, of potassium feldspar are common in the rocks, but are more abundant in the upper part of the unit than in the lower part. Cataclastic rocks are rare in the biotite-muscovite gneiss, although many rocks show small, discontinuous streaks of granulated minerals.

Modal analyses of the biotite-muscovite gneiss are given in table 7. The common rock of the unit is a muscovite-biotite-plagioclase-quartz gneiss, which may contain minor garnet, and locally potassium feldspar. In general the rocks are similar to those of the sillimanite gneiss unit except that layers of sillimanitic or sericitic gneiss are rare. The proportions of the major constituent minerals are about the same as in the sillimanite gneiss, although muscovite is commonly slightly more abundant. Garnet is less common than in the sillimanite gneiss, and where present is rarely more than 2 percent of the rock. Rare lenses contain no muscovite, and even rarer lenses contain no biotite and 50 percent muscovite.

The texture and characteristics of the minerals in the lower part of the biotite-muscovite gneiss unit are also similar to those of the sillimanite gneiss. In the upper part the rocks are commonly more schistose, and coarse plagioclase grains, as much as a centimeter in diameter are more common. The micas are commonly in coarse plates 2 or 3 mm in diameter. The schist in general resembles the schist in the Yantic Member of the Tatnic Hill Formation.

Calc-silicate gneiss (tc on pl. 2 and 4): Lenses of calc-silicate gneiss occur throughout the lower member of the Tatnic Hill Formation, but most commonly are in the lower part of the unit. Most of them are less than 5 feet thick and could not be traced beyond a given outcrop. The largest has a maximum apparent thickness of about 300 feet and could be traced along strike for about 4 miles in the Plainfield quadrangle (pl. 4). A smaller lens in the central part of the Danielson quadrangle is less than 100 feet thick and is cut off by faults on both ends. The calc-silicate gneiss is well layered, with layers a few inches thick, and shows strong internal folding. The rocks are similar in appearance and in general mineralogy to those of the Fly Pond Member.

The modal analysis of a sample of the calc-silicate gneiss is given in table 8 with the calc-silicate rocks of the Fly Pond Member.

The rock most commonly is a medium-light-gray to medium-gray, fine- to small-grained biotite-quartz-hornblende-plagioclase gneiss. Plagioclase is 25 to 40 percent of most rocks, hornblende is 20 to 40 percent, quartz is 10 to 30 percent, and biotite is 10 to 20 percent. Minor diopside, epidote, garnet, calcite and scapolite may be present, commonly in amounts less than 5 percent, in any rock. In general diopside and epidote are less common and less abundant than in the Fly Pond Member, and garnet, calcite and scapolite are more common though where present they are commonly in accessory amounts. Other accessory minerals include opaque minerals, sphene, apatite, zircon and locally allanite and rutile.

The noncataclastic calc-silicate gneiss is a fairly uniform, granular rock with an average grain size of about 0.5 mm. The grains commonly have smooth boundaries and quartz grains are weakly sutured or nonsutured. Most samples, however, show at least small streaks of granulated minerals, and many show fairly strong cataclasis. In these plagioclase has ragged boundaries, may be bent, fractured, myrmekitic, or sharply zoned. Hornblende also has ragged boundaries, and quartz is moderately sutured. Epidote and scapolite are most common in the cataclastic rocks, and probably formed from plagioclase and hornblende. Plagioclase composition is commonly An 40 to An 50. Pleochroism of biotite is from almost colorless to dark yellowish orange (10YR) or light brown (5YR). The Y and Z directions of hornblende are commonly dusky yellow green (5GY) though in many rocks hornblende may be partially bleached to a pale green, or altered to pale-green actinolite.

Amphibolite.--Lenses of amphibolite occur throughout the lower member, but are most abundant near the base of the unit. They vary in size from small pods less than a foot in diameter to several feet thick and tens of feet long. None could be traced with any certainty beyond an individual outcrop, and they are not shown separately on the geologic maps. The amphibolites are locally massive and unlayered, but more commonly they are layered. Thin, light bands of feldspathic gneiss, a few millimeters thick alternate with thicker bands of dark, mafic rich gneiss. Biotite flakes and hornblende prisms are commonly oriented in a plane parallel to the layering.

The amphibolites are dark-gray, fine- to medium-grained quartz-biotite-plagioclase-hornblende gneiss. Hornblende and plagioclase constitute about 75 percent of most amphibolites, and quartz and biotite may be as much as 10 percent each. Epidote is a common minor mineral, and may be abundant locally. Minor scapolite is also present locally. Accessory minerals include sphene, opaque minerals, rutile, zircon and apatite. Plagioclase is commonly An 45 to An 55. Pleochroism of the hornblende is Y, grayish green (10GY) and Z, dusky yellow green (5GY). Biotite is commonly light brown (5YR) to moderate yellowish brown (10YR).

Fly Pond Member

The Fly Pond Member of the Tatnic Hill Formation was named by Snyder (1961) as a member of the Putnam Gneiss of the Norwich quadrangle. It is a unit of calc-silicate gneiss between the lower member and the Yantic Member. The calc-silicate rock is nonresistant to erosion and is poorly exposed except where the rocks are cut by pegmatite, which is abundant in the Fly Pond Member, and most exposures of the unit are beneath or interleaved with pegmatite. The contact with the underlying gneisses of the lower member of the Tatnic Hill is not exposed in the Plainfield-Danielson area. In the southwest corner of the Danielson quadrangle exposures of the Fly Pond and the lower member are separated by only about

20 feet of till, and the contact is apparently sharp. The Fly Pond has a maxiumum apparent thickness of about 600 feet throughout most of the area but in the northern part of the Danielson quadrangle it thins to about 125 feet. The rocks of the Fly Pond Member are in the sillimanite grade of metamorphism, and only locally are cataclastic.

The Fly Pond Member consists of a nonrusty, light-medium-gray to medium-gray, small-grained gneiss with varying amounts of biotite, epidote, diopside, hornblende, quartz and plagioclase. The rocks are well layered in layers that are commonly a few inches thick, and the boundary between layers is sharp. The difference between layers is a difference in the proportion of mafic to felsic minerals in the layers. A fine scale lamination also occurs within layers, and is produced by thin (commonly less than 0.1 inch) quartz-feldspar rich laminae separated by thicker zones rich in mafic minerals. Biotite plates and hornblende laths are commonly oriented in a plane parallel to the layering and the lamination. Snyder (1961, 1964a and b) mapped a zone of marble within the Fly Pond Member of the Norwich, Fitchville and Willimantic quadrangles. No marble was observed in the Plainfield-Danielson area, but possibly unexposed marble underlies some of the larger valleys, such as the valley of Kitt Brook along the border of the Plainfield and Scotland quadrangles. The calc-silicate gneisses show little change on weathering except that biotite is bleached to a golden brown, and locally the rocks are slightly rusty.

Modal analyses of the Fly Pond Member are given in table 8. The rocks of the unit are epidote-hornblende-quartz-plagioclase gneisses with or without either or both biotite and diopside and commonly with minor potassium feldspar. Quartz and plagioclase are about equal in amount in most rocks; they range from 15 to 50 percent of the rock, and are commonly about 30 percent each. Hornblende constitutes 10 to 40 percent of the rock and is commonly about 25 percent. Either biotite or diopside may be present in amounts up to 15 percent, but in most rocks are less than 5 percent. Epidote may be as much as 20 percent of the rocks, but is also about 5 percent in most rocks. Potassium feldspar rarely makes up more than 5 percent of the rock, and is commonly less than 1 percent; it is most abundant and in largest grains adjacent to pegmatites. Local layers are epidote-biotite-quartz-plagioclase gneiss with minor or no hornblende, but these are rare. Accessory minerals include sphene, apatite, opaque minerals, rutile, zircon and allanite.

The rocks of the Fly Pond Member most commonly are granular gneisses with an average grain size of 0.5 to 1 mm. As a rule quartz and plagioclase are slightly coarser grained than the mafic minerals. Most grains have smooth, angular to slightly rounded boundaries. Quartz is only locally weakly sutured; in most rocks it is not sutured. The composition of the plagioclase ranges from An 40 to An 55. Plagioclase grains are commonly irregularly zoned, and may show a variation of 10 or 15 percent An within a single rock. Epidote is commonly associated with plagioclase, and some epidote occurs as oriented inclusions in the plagioclase. The strongest zoning is around the epidote, and probably the epidote is replacing plagioclase. The epidote commonly has a low birefringence, anomalous interference colors and a high negative optic angle; it apparently is a high alumina variety. Much epidote contains very fine, vermicular inclusions of a low index, low birefringent mineral (quartz?). Hornblende is megascopically a dark greenish gray, in contrast to the black hornblende of the Quinebaug Formation. In thin section, both the Y and Z directions are commonly dusky yellow green (5GY), though in some rocks Z is a grayish blue green (5BG). A pale green actinolite that may constitute as much as 5 percent of the rock, commonly occurs adjacent to or around the hornblende, and is probably a replacement of hornblende. Diopside is yellow green megascopically and colorless in thin section. The pleochroism of biotite is from almost colorless to yellow brown (10YR). The rocks of the Fly Pond Member are commonly fresh, and only locally contain chlorite after biotite and hornblende or sericite after plagioclase.

Yantic Member

The top of the Tatnic Hill Formation is marked by a micaceous schist called the Yantic Member. In the Plainfield-Danielson area, the Yantic Member is equivalent to Snyder's (1961) western unit of biotite-muscovite schist of the Putnam Gneiss in the Norwich quadrangle. Snyder used the name Yantic informally to distinguish these rocks from rocks of similar composition below the Fly Pond Member, and assigned the name for exposures near the village of Yantic near the western edge of the Norwich quadrangle. When the Putnam Gneiss was redefined, (Dixon, 1964) the name Yantic was retained because of common usage, and the unit was defined on the basis of a series of cliff exposures west of Tatnic Hill, along the border between the Danielson and Hampton quadrangle. In addition to the main belt of the member through the central part of the area, the unit also occurs on the western edge of the Hampton quadrangle, where it forms the eastern side of the Willimantic dome.

The rocks of the Yantic Member are fairly resistant to erosion and commonly form a highland. The contact with the underlying Fly Pond Member is exposed in several places near the base of hills held up by the more resistant Yantic Member, although in most places there is pegmatite along the contact. The contact is sharp and apparently conformable. Lenses of amphibolite are common in the Yantic Member, just above the lower contact. In the Plainfield-Danielson area the Yantic Member has a rather uniform thickness of about 1,000 feet, and does not appear to thin to the north as does the rest of the Tatnic Hill Formation.

The rock of the Yantic Member is typically a nonrusty, small-grained, dark-gray micaceous schist with coarse mica plates. Interlayered with the mica schist is a granular schist of about the same composition, although commonly with less abundant muscovite, and with small-grained micas. The rock commonly contains megacrysts of plagioclase as much as 1.5 inches in diameter; microcline megacrysts are also prominent near pegmatites. Local lenses, slight rusty weathering, of aluminum-silicate schist are interlayered with the Yantic Member; on the west side of the unit these contain staurolite or, less commonly kyanite, and on the east side they contain sillimanite. The lenses are small, and most of them cannot be traced beyond a given outcrop. The amphibolite lenses near the base of the unit are also small, rarely more than 10 feet thick. Pegmatites are common throughout the member, but are especially abundant near the contact with the Fly Pond. It is rare to find an outcrop of the Yantic without some pegmatite in it, and locally the schist has been converted to migmatite. Foliation in the Yantic Member is mainly a schistosity formed by orientation of the mica flakes. The rocks are layered, both on a large scale of several inches to a foot of alternating coarse schist and granular schist, and on a small scale of lamination of less than an inch thick within the thicker layers. The layering is commonly parallel to the schistosity and the boundaries between layers, and between the small scale laminations are sharp. Minor cataclastic deformation is fairly common in the rocks; many of them are mortar gneisses, and locally they are well-laminated mylonites.

Modal analyses of several samples of the Yantic Member are given in table 9. The common rock of the unit is a muscovite-biotite-plagioclase-quartz schist. Quartz is generally slightly more abundant than plagioclase, and biotite is more abundant than muscovite. Quartz constitutes 30 to 55 percent of most rock, and is commonly about 40 percent; plagioclase is 15 to 50 percent and commonly about 35 percent; and biotite is 5 to 25 percent and commonly about 15 percent. In the coarse mica schist muscovite constitutes 10 to 20 percent of the rock (table 9, S8-90; S8-190) and in the granular schist it is 0 to 5 percent (table ~~8~~ 9, S7-68; S7-89). Potassium feldspar, commonly as microcline, occurs locally adjacent to pegmatites, and may form coarse grains. Garnet may make up 1 or 2 percent of the schist, and rare lenses may contain as much as 50 percent garnet. Accessory minerals in the Yantic member include epidote, apatite, opaque minerals, zircon and locally tourmaline.

The lenses of aluminum-silicate schist in the Yantic Member are in general compositionally similar to the rest of the unit except for the presence of staurolite, kyanite (table 9, S1-146) or sillimanite (table 9, S7-91). In addition muscovite is commonly more abundant than biotite, and plagioclase is less abundant than in the rest of the unit. These schists are more susceptible to retrogression than the other schist of the Yantic, and sericite after the aluminum-silicate minerals, especially sillimanite, and plagioclase, may constitute 25 percent of the rock. Biotite also may be strongly chloritized. The Yantic Member along the western edge of the Hampton quadrangle commonly contains minor, fresh sillimanite evenly distributed in the rock.

The amphibolite near the base of the Yantic Member is a layered to massive, dark-gray, small- to medium-grained rock composed of 50 to 70 percent hornblende, 20 to 35 percent plagioclase, 5 to 10 percent quartz and 0 to 5 percent biotite (table 9, S7-57). Epidote is a common accessory mineral and locally may be a major one. Other accessory minerals include sphene, rutile, opaque minerals, apatite and zircon. Most of the amphibolite is layered, with thin (0.1 inch or less), white stripes of plagioclase between thicker (about 1 inch) hornblende rich bands.

The noncataclastic schists of the Yantic Member contain granular, even grains of quartz and plagioclase with an average size of about 0.5 mm. Quartz grains show minor undulose extinction and are not sutured. The composition of the plagioclase is commonly An 25 to An 35. In rocks which contain microcline, a minor amount of myrmekite is developed adjacent to it. In the coarse schists the micas are as much as 3 mm long, and in the granular schists they are commonly about 0.5 mm long. The color of the biotite is somewhat variable; in over half the samples Z is yellow brown (10YR), but olive (10Y) and olive brown (5Y) are also common. Garnet, where present, is commonly in sparse grains less than 0.5 mm diameter. In the local garnet rich lenses, however, it may form poikiloblastic grains an inch or more in diameter. The rocks are commonly fresh and show only minor alteration of plagioclase to sericite or of biotite to chlorite. Some of the accessory epidote may be a replacement of plagioclase. The amphibolites are commonly granular rocks with an average grain size of 0.5 to 1 mm. The composition of the plagioclase is An 40 to An 60; the lower An content is more common. The color of the biotite shows the same variation as it does in the schists. The hornblendes commonly are Y, dusky yellow green (5Y) and Z, grayish blue green (5G).

Many of the rocks of the Yantic Member are somewhat cataclastic, and throughout the unit mortar schists are interlayered with noncataclastic schists. In these rocks streaks of fine- to very-fine-grained, granulated quartz, plagioclase and biotite separate layers of small grained minerals (table 9, S8-90, S7-68). Quartz grains are commonly weakly to moderately sutured. Mylonite, or blastomylonite, was observed only at two localities. West of Wolf Den Brook in the northern part of the Danielson quadrangle (D-33.9N; 26.5W) the Yantic Member is in fault contact with the Hebron Formation. Progressive cataclasis of the rocks can be observed from about 5 feet away inward toward the fault, and within a few inches of the fault the rock is a blastomylonite. The rock contains small-grained, sericitized plagioclase in a matrix of very-fine-grained chlorite and indistinguishable quartz and feldspar. Blastomylonite also occurs in the southern part of the area on the east bank of the Shetucket River (S-1.5N; 23.7W), although no fault was observed here. The rocks consist of streaks of fine-grained sericite as much as 5 mm wide, and containing minor brown biotite, chlorite, opaque minerals and very-fine-grained quartz. The streaks separate bands of sutured quartz, plagioclase and biotite, which are granulated but less altered.

Age and correlation of the Tatnic Hill Formation

Within the Plainfield-Danielson area the only age that can be established for the Tatnic Hill Formation is a relative one; it is younger than the Quinebaug Formation and older than the Hebron Formation. The unit is correlated with the Brimfield Formation of the western and central parts of eastern Connecticut (pl. 1). Brimfield is tentatively dated as middle Ordovician by correlation with the Partridge Formation of New Hampshire (Cady, 1960; Billings, 1956; Harwood, 1967). The Tatnic Hill Formation is, therefore, tentatively dated as middle Ordovician.

The Tatnic Hill Formation traces from the type area south to the Honey Hill fault, and then southwest as a narrow belt above the fault, into the east limb of the Chester syncline and its continuation, the Hunts Brook syncline (Snyder, 1964a; Lundgren, 1963, 1964, 1966a, 1967; Goldsmith, 1961; see also pl. 1). Brimfield Schist traces from the northern part of eastern Connecticut into the west limb of the Chester-Hunts Brook syncline. The Brimfield of northern Connecticut, and of Massachusetts has, at least in part, been mapped by Robinson (1967) and Peper (1967) as Partridge Formation, and traced into Partridge Formation in New Hampshire. The middle Ordovician age of the Partridge Formation is based in part on its position above the middle Ordovician Ammonoosuc Volcanics and unconformably beneath fossil bearing lower Silurian Clough Formation (Billings, 1956; Cady, 1960) and more recently by correlation with middle Ordovician fossil bearing slates in western Maine (Harwood, 1967).

The units of the Tatnic Hill Formation have been followed by reconnaissance northward into Massachusetts where they are continuous with several different units on Emerson's (1917) map. The lower member traces into a zone of Emerson's "gneisses and schists of undetermined age", and a lens of Brimfield Schist. The Fly Pond Member within the Connecticut overlap of his map is also shown as Brimfield Schist which lenses out just south of the state line, and in southern Massachusetts the Fly Pond is part of the "gneisses and schists of undetermined age". The Yantic Member is included in this same unit in Connecticut, but just north of the state line it traces into a belt of Worcester Phyllite; this one belt of Worcester through the west side of the village of Webster is probably the only one on Emerson's map which is equivalent to part of the Tatnic Hill Formation.

Zartman and others (1965) report a discordant uranium-thorium-lead isotopic analysis of a zircon from a pegmatite that cuts, or occurs in, the Fly Pond Member of the Tatnic Hill Formation in the Norwich quadrangle. They state (1965, p. D5) "....both episodic and continuous diffusion models indicate an age of greater than 500 million years (middle Ordovician or older) as does the Pb^{207}/Pb^{206} age by itself, for this single zircon". The assignment of an age of middle Ordovician or older for a number "greater than t00 m.y." is hard to understand, however, as by either the Holmes (1960) or Kulp (1961) time scale (which put the Ordovician-Cambrian boundary at 500 m.y.) this would have to indicate a Cambrian age for the pegmatite, and Cambrian or older age for the Fly Pond Member, since the pegmatite is presumably younger than the rock in which it occurs. This one discordant isotopic analysis, however, would not seem to be sufficient evidence on which to base any firm age assignment, and until more information is available, regional correlation still offers the best indication of the age of the Tatnic Hill Formation.

Origin and chemical composition

The Tatnic Hill Formation consists of a metamorphosed pile of eugeosynclinal sedimentary rocks. The protolith for the graphite bearing rusty weathering gneiss at the base of the unit was probably a carbonaceous black shape. The rest of the lower member consisted primarily of interlayered graywackes, shales and siltstones, with subsidiary calcareous shales. The amphibolites in the lower part of the unit may have been dolomitic sediments or may have been mafic volcanic rocks. The rocks of the Fly Pond Member represent a stage of deposition of calcareous shale and locally limestone. The rocks of the Yantic Member were predominantly shales, which were locally aluminous.

Chemical analyses of several samples of the Tatnic Hill Formation are given in table 20 (analyses 1 to 7, 12 and 13). The analyses are generally comparable to analyses of graywackes and shales listed by Pettijohn (1963, table 6; 1957, table 51). According to Pettijohn (1963, p. S7) typical graywackes should have an excess of Na_2O over K_2O, whereas the reverse is true in most of the analyses in table 20. Some K_2O may have been introduced during metamorphism, or possibly the original sediments contained a higher proportion of shaley material than many graywackes.

The chemical analyses were recalculated into mesonorms using the methods and standard formulae of Barth (1959) though with some variation depending on the mineral composition of the rock. For rocks which contain primary metamorphic muscovite, excess K (after computing biotite) was calculated as muscovite; in sample S7-45 and the calc-silicate rocks in which any muscovite present is retrogressive, excess K was calculated as orthoclase which is present in the rocks. For the calc-silicate gneisses an alumina bearing hornblende was calculated rather than the alumina-free actinolite, as this gave a better correlation with the modal analyses. In general the mesonorms correspond fairly closely with the rock modes. As a rule in samples which contain less than 5 percent C, the excess Al is accommodated in garnet and probably as excess Al in the micas. Those rocks in which C is 5 percent or greater contain sillimanite. The Wo in the mesonorm of S7-77 is probably a reflection of the epidote in the rock.

A plot of the A:C:F: ratios of the analysed metasedimentary rocks of the Plainfield-Danielson area, is given in figure 5. Also included in the diagram are analyses from the Norwich and Fitchville quadrangle

(Snyder, 1964a) and the Deep River and Essex quadrangles (Lundgren, 1966b). The A:C:F: ratios were computer calculated by the following formulae: $A = Al_2O_3 + Fe_2O_3 - (Na_2O + K_2O)$; $C = CaO - (3P_2O_5 + CO_2)$; $F = MgO + FeO + MnO$. The micaceous schists and gneisses of the Tatnic Hill Formation are generally limited by the line 20 C: 80 A-F, and the ratios for the Brimfield Schist fall within the same field. The ratios for the Fly Pond Member fall within the boundary of 30 - 45 C: 70 - 55 A-F.

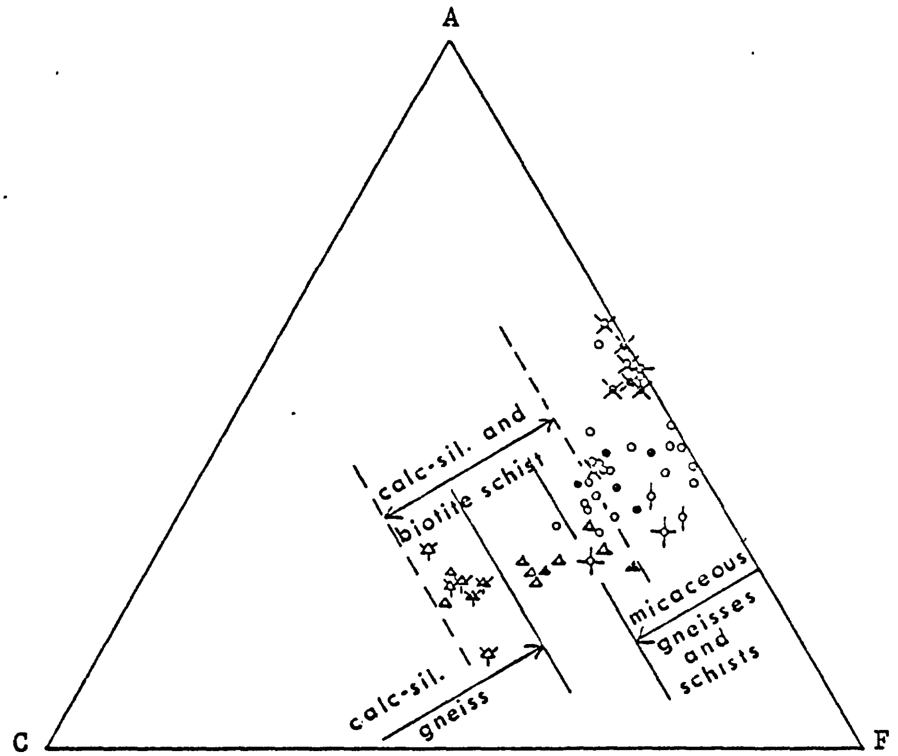


Figure 5.--Triangular diagram showing A:C:F: ratios of the analysed metasedimentary rocks of eastern Connecticut, where $A = Al_2O_3 + Fe_2O_3 - (Na_2O + K_2O)$; $C = CaO - (3P_2O_5 + CO_2)$; $F = MgO = FeO = MnO$ in molecular proportions.

	Dixon (this report)	Snyder (1964a)	Lundgren (1966)
Tatnic Hill Formation; micaceous gneisses of lower and Yantic members-----	●	○	⌖
Brimfield Schist; micaceous gneiss-------------		-o-	ϕ
Scotland Schist; micaceous schist-------------	✱	⌘	
Hebron Formation; calc-silicate schist and biotite schist------------	▲	△	
Tatnic Hill Formation; calc-silicate gneiss of Fly Pond Member-----------	✶	✡	

Table 6.--Modal analyses of the lower part of the lower member of the Tatnic Hill Formation.

	Rusty weathering gneiss (tr)			Garnet-biotite gneiss (tb)					
	P1-107	P1-62	D3-90	P1-45	P1-98	P1-81	D2-353	D2-413	P1-135
Quartz	42	32	7	49	45	37	34	51	9
Plagioclase	6	26	5	42	35	12	20	28	33
Potassium feldspar				x		8	16		19
Granulated quartz-feldspar	2								3
Biotite		11	13	7	14	19	14	9	30
Muscovite	37 5/	5		1	0.4 5/				5 5/
Sillimanite		2	2			9	5		
Kyanite			21						0.1
Garnet	0.2	4	31			12	7	11	0.6
Hypersthene					3				
Epidote				0.2 4/		x		0.1 4/	
Opaque minerals	2 6/	0.3 6	3 6/	0.2	0.1	1	3	0.2	0.5
Rutile		2	0.7	x				0.4	x
Zircon				x	x	x	0.2	x	x
Apatite				x	0.1			0.1	
Sphene						x			
Limonite	7	7	18		2				
Chlorite 1/	4(b,g)					0.1(g)		0.1(g)	x(b)
Sericite 2/	(s,p,g)	11(p,s)		0.3(p)		1(g,p)		0.4(p)	x(p)
Calcite 3/				x(p)					
Plag. comp.	An25-30	An33	An33	An42	An40	An33	An30	An33	An23-28

Percentages rounded off to the nearest whole number, except those less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.

1/ Chlorite after (b) biotite, (g) garnet.

2/ Sericite after (p) plagioclase, (s) sillimanite, (g) garnet.

3/ Calcite after (p) plagioclase.

4/ Epidote secondary after plagioclase.

5/ Muscovite gradational into sericite and is probably all recrystallized sericite after plagioclase and sillimanite; in P1-107 sericite was counted with muscovite.

6/ Opaque is primarily graphite.

Lower member of the Tatnic Hill Formation:

Rusty weathering gneiss unit (tr)

Pl-107 (P-26.3N; 28.1W): Grayish-red, grayish-orange and medium-light-gray, fine-grained feldspar-muscovite-sericite quartz gneiss. Color is due to weathering; fresh rock in a new road cut 100 feet north was medium-dark gray. Rock resembles a conglomerate but is a blastomylonite gneiss. Lens shaped clasts about 1/2 inch long consist of granulated, strongly sutured quartz and sericitized feldspar. The clasts are separated by streaks of fine-grained sericite-muscovite, quartz, feldspar, chlorite and limonite. Rock is crossed by numerous fine fractures subparallel to the streaks of fine-grained minerals, and filled with limonite. No sillimanite is left in the thin section, but sericite pseudomorphous after sillimanite occurs on the weathered surface, and some sericite of the rock is after sillimanite. The sample contains black spots about 0.1 inch in diameter which are almost completely altered garnet. The grain size averages less than 0.1 mm.

Pl-62 (P-4.6N; 31.8W): Grayish-orange, dark-yellowish-orange, and pinkish-gray; fine- to coarse-grained graphite-sillimanite-garnet-muscovite-biotite-plagioclase-quartz gneiss. Color is due to weathering. Rock is similar to Pl-107 except that it is not so strongly neomineralized. Clots of quartz and feldspar several inches long and about 1/2 inch thick contain cores of pale-blue feldspar; they are bordered on either side by fine-grained quartz-mica schist with moderate red garnets 1/4 inch in diameter. The feldspar cores are coarse, partially sericitized plagioclase surrounded by granulated, strongly sutured quartz and fresh fine-grained feldspar. Limonitic fractures cross the sample, and most limonite of the rock is in the fractures. Biotite is light brown (5YR 4/4). Coarse muscovite flakes are commonly bent and may show kink bands; biotite is less commonly bent. Average grain size is about 0.1 mm.

D3-90 (D-0.3N; 25.1W): Grayish-orange, pale-reddish-brown, and medium-bluish-gray, medium- to coarse-grained sillimanite-plagioclase-biotite-garnet-kyanite gneiss. Color is due to weathering. A thin quartz vein (0.1 mm) accounts for the majority of quartz in the mode. Medium-bluish-gray-kyanite, minor sillimanite and pale-red garnet stand out on the weathered surface. Garnet grains contain abundant inclusions of sillimanite, and less abundant kyanite and biotite. Biotite is moderate red brown (10R 4/6), and contains rutile needles. Grain size is variable; garnet, kyanite and plagioclase are commonly 0.5 mm or more.

Garnet-biotite gneiss unit (tb)

P1-45 (P-42.8N; 26.2W): Medium-gray, medium- to coarse-grained porphyroblastic potassium feldspar-biotite-plagioclase-quartz gneiss. Only a few very-fine grains of potassium feldspar occur in the thin section, but the sample contains megacrysts as much as 1/2 inch long of clear, moderate-orange-pink potassium feldspar. Plagioclase also forms megacrysts of about the same order or size. Foliation is defined by planar orientation of most biotite flakes parallel to an irregular banding of biotite rich bands between quartz and feldspar rich bands. A few streaks of granulated quartz and feldspar parallel the biotite orientation, or occur along the edges of the coarse plagioclase grains. Quartz grains show undulose extinction and moderate suturing. Biotite is moderate olive brown (5Y 4/4). Average grain size is 0.7 mm.

P1-98 (P-23.8N; 26.7W): Medium-light-gray, slightly rusty weathering, fine-grained pyroxene-biotite-plagioclase-quartz gneiss. Foliation is defined by orientation of biotite plates and by a weak layering with quartz and feldspar rich layers 0.1 inch thick alternating with thicker mafic rich layers. Rock is a mortar gneiss with small grains of plagioclase, hypersthene and quartz and fine-grained biotite in a very-fine-grained matrix of strongly sutured quartz, plagioclase and biotite. The small-grained quartz is moderately sutured and shows undulose extinction. Biotite is moderate brown (5YR 4/4). Grain size is variable.

P1-81 (P-15.5N; 28.7W): Dark-gray, medium-grained sillimanite-garnet-biotite-feldspar-quartz gneiss. Foliation is defined by orientation of biotite flakes and thin discontinuous quartz and feldspar rich streaks. Skeletal grains of garnet as much as 1/4 inch diameter are filled with quartz and biotite inclusions. More commonly the garnet is subhedral, moderate-red grains 0.05 inch in diameter. Small garnet, plagioclase and quartz grains are in a very-fine-grained, granulated matrix of moderately sutured quartz, plagioclase, and biotite. Euhedral sillimanite and fine-grained, potassium feldspar occur in biotite rich streaks. Biotite is moderate brown (5YR 3/4). Grain size is variable.

D2-353 (D-9.0N; 25.5W): Medium-gray, small-grained sillimanite-garnet-biotite-feldspar-quartz gneiss. Sample is similar to P1-81, except that it contains a 1 inch megacryst of clear, pale-red potassium feldspar, probably orthoclase, surrounded by a felsic mantle 0.1 inch thick, consisting primarily of granulated and strongly sutured quartz and myrmekitic plagioclase. The orthoclase is not twinned, but contains streaks of very-fine blebs of an unidentified mineral, possibly quartz, and also streaks of fine sillimanite grains. The rest of the rock contains fine streaks of granulated quartz, plagioclase and biotite separating small grains of quartz, feldspar and garnet. Quartz is moderately sutured and the larger grains show undulose extinction. Biotite is moderate brown (5Y 3/4). The average grain size is variable, but the nongranulated grains average about 0.3 mm.

D2-413 (D-20.9N; 21.3W): Banded, brownish-gray and very-light-gray, fine-grained biotite-garnet-quartz-feldspar gneiss. Rock is slightly rusty weathering. Quartz-feldspar band an inch thick is bordered on either side by biotite-garnet rich layers. Thin section shows a few, thin, discontinuous streaks of granulated minerals; most of the rock is of fairly uniform, granular minerals. Quartz is weakly sutured. Biotite is light brown (5YR 5/6). Average grain size is 0.4 mm.

P1-135 (P-38.7N; 23.2W): Dark-gray, fine-grained quartz-biotite-feldspar mylonite gneiss. Coarse feldspar grains, as much as 1/2 inch diameter, are commonly surrounded by a fine shell of granulated feldspar which extends beyond the core grain as a long, thin layer. Some of the strung out feldspar grains are twisted and rotated. In thin section medium to coarse, fresh, fractured and bent feldspar grains are in a very-fine-grained matrix of quartz, feldspar and biotite; fractures are filled with very-fine-grained quartz and feldspar. Plagioclase in the matrix is fresh to strongly sericitized. Fine-grained biotite occurs in streaks which alternate with biotite poor streaks. Some quartz is strongly sutured and other is granular. Biotite is moderate brown (5YR 4/4) and commonly contains rutile needles. Grain size is variable.

Table 7.--Modal analyses of part of the lower member of the Tatnic Hill Formation

	Sillimanite gneiss (ts)					(tbm) Biotite-muscovite gneiss		
	P1-95	P1-49	S7-45 *	S7-145	S7-40 *	S8-172 *	S8-171	S8-159 *
Quartz	46	43	42	36	32	51	48	39
Plagioclase	8	20	21	15	16	22	18	34
Potassium feldspar			2	0.7		x		
Biotite	12	12	21	26	23	15	6	20
Muscovite	3 5/	14 5/	1 5/	13 5/	4 5/	8	2 5/	3
Sillimanite		1	4		6			
Garnet	1		3		0.2	1		
Kyanite		0.2						
Opaque minerals	1	4	2	1	4	2	3	3
Zircon	x	0.2	0.2	x	x	x	x	0.2
Monazite			0.1	x	x	0.1	x	
Apatite		x		0.2		0.2	0.1	
Tourmaline							x	
Epidote 1/	2		x	3		0.2		0.4
Chlorite 2/	0.3(b,g)	2(b)	x(b,g)	1(b)	x(b)	0.2(b,g)	6(b)	x(b)
Sericite 3/	26(p,g,s?)	4(p,s)	4(p,s,g)	3(p,s)	15(s,p)	0.4(p,g)	16(p)	x(p)
Calcite 4/							0.2(p)	
Approx. Plag. comp.	An30	An30	An33	An27	An25	An27	An30	An30

Percentages rounded off to the nearest whole number, except those less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.
*Samples for which chemical analyses are reported in table 20.
1/ Epidote secondary after plagioclase.
2/ Chlorite after (b) biotite, (g) garnet.
3/ Sericite after (p) plagioclase, (g) garnet, (s) sillimanite.
4/ Calcite after (p) plagioclase.
5/ Muscovite is secondary after plagioclase or recrystallized sericite; in samples P1-49 and S7-145 some muscovite is secondary and some is primary metamorphic.

Lower member of the Tatnic Hill Formation:

Sillimanite Gneiss unit (ts)

P1-95 (P-17.9N; 32.1W): Medium-dark-gray, very-fine-grained garnet-plagioclase-biotite-quartz mylonite. Rock is thinly laminated, and contains dull pinkish-gray, rounded or flattened lenses of plagioclase, less than 0.1 inch, in a very-fine-grained matrix. Small black spots in the rock are retrogressed garnet. In thin section the cataclastic foliation is shown by crinkled bands of very-fine-grained, granular quartz, separated by streaks, commonly very thin, of sericite and biotite. The bands are deflected around small knots of ungranulated plagioclase, commonly sericitized, or of garnet. Garnet is partially to completely altered to chlorite, sericite and garnet. Biotite is moderate olive brown (5~~H~~Y 4/4). Average grain size is less than 0.1 mm. (Pl. 10, fig. 3 and 4.)

P1-49 (P-35.8N; 31.0W): Medium-dark-gray, small-grained muscovite-biotite-plagioclase-quartz gneiss. Foliation is defined by planar orientation of the micas, and by quartz and feldspar lenses alternating with biotite rich lenses, commonly less than 0.1 inch thick. Small-grained quartz shows undulose extinction and moderate suturing; quartz in the micaceous streaks is fine to very fine grained. Kyanite and most sillimanite are surrounded by muscovite. Biotite is moderate olive brown (5Y 4/4). Average grain size is about 0.3 mm.

S7-45 (S-5.1N; 1.5W): Medium-dark-gray, small-grained garnet-sillimanite-biotite-plagioclase-quartz gneiss. Micas are small and evenly disseminated through the sample. Foliation is weak and is defined mainly by a weak biotite orientation. Small quartz grains show undulose extinction and moderate suturing. Fine fractures cross the sample and adjacent to them minerals are granulated and biotite is dragged parallel to them. Potassium feldspar shows microcline twinning. Garnet is in elongate moderate red crystals, colorless in thin section, and contains abundant fine needles of sillimanite. Sillimanite is mostly in fresh needles as much as 1/4 inch long. Biotite is olive gray (5Y 3/2). Average grain size is about 0.4 mm.

S7-145 (S-4.8N; 9.1W): Dark-gray, small-grained muscovite-plagioclase-biotite-quartz schist. A mica-quartz-feldspar pegmatite, containing coarse potassium feldspar, and about an inch thick cuts one corner of the sample. Foliation is defined by planar orientation of the micas. In thin section the rock is a mortar gneiss, with streaks of very-fine-grained granulated quartz and biotite separating ungranulated grains of quartz and feldspar. About half of the biotite is granulated and the other half is in small grains. The ungranulated quartz grains show weak suturing. Plagioclase is partially altered, and the epidote is probably a secondary mineral after plagioclase. Biotite is grayish brown (5YR 3/2). The average grain size is variable, and the ungranulated grains average about 0.4 mm.

S7-40 (S-6.3N; 6.8W): Medium-gray, small-grained sillimanite-biotite-sericite-plagioclase-quartz gneiss. Foliation is defined by orientation of biotite flakes and by alternating lenses of quartz and plagioclase and of biotite and sillimanite-sericite. On the weathered surface are greenish-gray lenses of sericite with matted sillimanite needles. In thin section most of the sillimanite is in lenses with sericite-muscovite and biotite. Most of the muscovite grades into sericite, and probably is recrystallized from the sericite; some may be primary metamorphic. No potassium feldspar was observed in the rock, but some of the plagioclase is myrmekitic. The myrmekite is adjacent to discontinuous streaks of granulated mineral. Quartz is moderately sutured. Biotite is moderate yellow brown (10YR 5/4). Average grain size is about 0.4 mm.

Biotite-muscovite Gneiss unit (tbm)

S8-172 (S-5.2N; 9.0W): Medium-gray, small-grained, garnet-muscovite-biotite-quartz-feldspar gneiss, with coarse plagioclase grains as much as 1/4 inch diameter. Foliation is defined by orientation of coarse mica plates and by alternating quartz and feldspar rich layers and micaceous layers. Grains are mostly granular; quartz is weakly sutured. Biotite is moderate olive brown (5Y 4/4). Average grain size is about 0.5 mm.

S8-171 (S-5.2N; 8.9W): Medium-dark-gray, small-grained biotite-plagioclase-quartz gneiss. Foliation is defined by thin quartz lenses and feldspar streaks as much as 1 inch long separated by biotite rich layers. The thin section shows thin streaks of granulated grains. Quartz shows strong undulose extinction and fairly strong suturing. Plagioclase is commonly partially sericitized. Biotite is moderate olive brown (5Y 4/4). Average grain size is about 0.7 mm.

S8-159 (S-8.4N; 15.8W): Medium-gray, medium-grained muscovite-biotite-feldspar-quartz gneiss. Foliation is defined by planar orientation of the mica plates and feldspar laths. Feldspar grains are as much as 0.2 inch diameter. Grains are granular in shape; plagioclase grains are commonly somewhat larger than quartz. Quartz shows moderate undulose extinction, but grains are not sutured. Biotite is moderate olive brown (5Y 4/4). Average grain size is about 0.5 mm.

Table 8.--Modal analyses of calc-silicate gneisses in the Tatnic Hill Formation

	Fly Pond Member				Lens in lower member
	S7-121 *	H9-14	S7-77 *	S8-174	P1-52
Quartz	38	34	29	27	26
Plagioclase	34	31	28	29	27
Potassium feldspar	0.1	1	6	0.2	x
Biotite	1	0.2	1	10	12
Hornblende	25	17	22	25	28
Colorless Actinolite		2	5		1
Diopside		8	3	1	x 1/
Epidote	0.2	6	4	6	2
Scapolite					2
Calcite					1
Opaque minerals			x	x	x
Sphene	1	1	2	1	1
Apatite	0.3	0.2	0.1	0.3	0.5
Zircon	x	x	0.1	x	0.1
Allanite	x		x	x	
Comp. of Plag	An45-55	An45	An47	An48	An40

Percentages rounded off to the nearest whole number, except those less than 1 percent;
x indicates minerals present in amounts less than 0.1 percent.
* Samples for which chemical analyses are reported in table 20.
1/ No diopside in thin section, but minor is present in hand sample.

Calc-silicate gneisses in the Tatnic Hill Formation:

<u>Fly Pond Member</u>

S7-121 (S-3.4N; 22.5W): Medium-gray, small-grained hornblende-plagioclase-quartz gneiss. Hornblende is dark greenish gray. Foliation is defined by parallel arrangement of quartz stringers, plagioclase and hornblende laths, giving the rock a fine scale layering. Sample contains a small quartz-feldspar pegmatite as much as 1/2 inch thick, which is partly concordant with the foliation and partly cuts it at a high angle. The rock has a uniform, granular texture, with an average grain size of about 0.7 mm, although quartz and feldspar grains are slightly larger than hornblende. Quartz is not sutured. Plagioclase may be zoned, from about An 45 to An 55. A few fine grains of allanite occur as inclusions in hornblende, and are surrounded by a strong halo. The minor biotite is moderate yellow brown (10YR 5/4). The Y and Z directions of hornblende are dusky yellow green (5GY 5/2).

H9-14 (H-4.7N; 0.6W): Medium-light-gray, small-grained epidote-diopside-hornblende-plagioclase-quartz gneiss. Foliation is defined by thin (less than 0.1 inch) quartz and feldspar rich laminae. Diopside is dusky-yellow green, epidote is grayish-yellow and hornblende is greenish-black. Quartz and feldspar are granular, have smooth boundaries and are commonly a little coarser than hornblende and diopside. Quartz is not sutured. Epidote is in irregular vermicular grains commonly associated with plagioclase, and the adjacent plagioclase is zoned. Biotite is dark yellow orange (10YR 6/6). The Y and Z directions of hornblende are dusky yellow green (5GY 5/2). The average grain size is about 0.8 mm.

S7-77 (S-6.9N; 21.2W): Medium-light-gray, small-grained biotite-epidote-diopside-hornblende-plagioclase-quartz gneiss. The appearance is similar to H9-14. Small, sparse biotite flakes are orientated parallel to lamination, and are bleached to a golden-olive-brown on the weathered surface. In thin section the rock is also similar to H9-14. The potassium feldspar is in small grains of microcline; a minor amount of myrmekite is adjacent to the microcline. Biotite is moderate yellow brown (10YR 5/4). Y and Z of hornblende are dusky yellow green (5GY 5/2). The average grain size is about 0.6 mm.

S8-174 (S-17.5N; 3.5W): Light-olive-gray, slightly rusty weathering, small-grained epidote-biotite-hornblende-plagioclase-quartz gneiss. Foliation is defined by parallel arrangement of biotite flakes, hornblende laths and thin plagioclase rich laminae. Minor granulati of minerals occurs in streaks parallel to the foliation. Quartz shows strong undulose extinction and weak suturing. Epidote is similar to that in H9-14 and S7-77. Biotite is dark yellow orange (10YR 6/6). Hornblende is dusky yellow green (5GY 5/2). The average grain size is about 0.5 mm, but is variable.

Lens in the lower member

P1-52 (31.1N; 27.2W): Medium-light-gray, fine-grained, epidote-biotite-hornblende-quartz-plagioclase gneiss; minor diopside is visible in the hand sample, but none was included in the thin section. The foliation is defined by quartz and feldspar rich laminae about 0.1 inch thick which are parallel to the biotite orientation. Biotite is bleached to golden dusky yellow on the weathered surface. Quartz grains are weakly sutured. Sample contains a few, fine grains of untwinned potassium feldspar and minor myrmekite is devloped in the adjacent plagioclase. Granulated streaks of quartz and plagioclase are parallel to the foliation. Near the granulated streaks hornblende is commonly bleached to colorless and partially altered to epidote and plagioclase is replaced by scapolite. Biotite is dark yellow orange (10YR 6/6). Hornblende is dusky yellow green (5GY 5/2).

Table 9.--Modal analyses of the Yantic Member of the Tatnic Hill Formation

	S8-90 *	S7-68 *	S8-190	S7-89	S7-91	S1-146	S7-57
Quartz	52	49	37	39	37	8	9
Plagioclase	18	14	27	36	6	0.2	17
Biotite	15	14	21	22	2	0.4	0.4
Muscovite	13	3	14	3	9	50	
Sillimanite					1		
Staurolite						20	
Kyanite						3	
Garnet	0.1	2		x	9	0.1	
Epidote	0.1			x			16
Hornblende							57
Sphene							1
Zircon	0.1	0.3	x	x	x	0.1	
Apatite	0.5	x	x	0.1	x	0.1	
Tourmaline						0.4	
Opaque minerals	0.7	2	1	0.5	2	4	
Limonite						0.7	
Chlorite 1/		0.2(b)	x(b)		12(b,g)	7(b,g,st)	
Sericite 2/	x(p)	15	x(p)		22(s,p,g)	5(k,st,g,p)	
Plag. comp	An28	An28	An25	An30			An60

Percentages rounded off to the nearest whole number, except those less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.

* Samples for which chemical analyses are reported in table 20.

1/ Chlorite from (b) biotite, (g) garnet, (st) staurolite.

2/ Sericite from (p) plagioclase, (s) sillimanite, (k) kyanite, (st) staurolite.

Yantic Member:

S8-90 (S-19.8N; 3.7W): Medium-dark-gray, fine-grained muscovite-biotite-plagioclase-quartz mortar gneiss. Muscovite plates are coarse. Foliation is defined by planar arrangement of mica plates and by a crude layering of quartz and feldspar layers and of micaceous layers. Streaks of granulated quartz, plagioclase and biotite separate bands of ungranulated minerals; the granulated areas include about 3/4 of the sample. Most quartz is in very-fine, granular grains with weak suturing; between the granulated streaks quartz is small grained and weakly sutured. Most biotite is granulated to very fine grained, although some small-grained biotite occurs with the coarse muscovite laminae. Muscovite is bent but is not granulated. Biotite is dark yellow brown (10YR 4/2). Grain size is variable.

S7-68 (S-5.4N; 23.5W): Medium-dark-gray, small-grained garnet-biotite-plagioclase-quartz mortar gneiss. Dark, fine-grained, micaceous laminae as much as 0.1 inch thick separate quartz and feldspar laminae, and are deflected around coarse plagioclase grains. The coarse plagioclase may be as much as 1/2 inch diameter. In thin section the dark laminae consist of very-fine-grained, granulated quartz, biotite and sericite-muscovite. In the quartz-feldspar laminae streaks of small- to fine-grained, elongated quartz grains are separated by very thin streaks of sericite. Biotite is grayish olive (10Y 5/4). Grain size is variable.

S8-190 (S-45.0N; 1.4W): Dark-gray, small-grained muscovite-biotite-plagioclase-quartz schist, with medium-grained micas. Foliation is primarily a schistosity formed by the mica plates, and by alternating, thin mica rich and quartz-feldspar rich laminae. Coarse plagioclase is as much as 1/2 inch long. Quartz and plagioclase are even, granular minerals with an average size of about 0.6 mm. Mica flankes are as much as 3 mm long. Quartz is not sutured. Biotite is moderate olive brown (5Y 4/4). This is the typical schist of the Yantic Member.

S7-89 (S-0.6N; 23.9W): Dark-gray, small-grained muscovite-biotite-plagioclase-quartz granular schist. Coarse plagioclase grains are as much as 1/4 inch long. Quartz and plagioclase are granular; quartz is commonly finer grained than plagioclase, and is not sutured. Biotite is light olive brown (5Y 5/6). Average grain size is 0.5 mm.

S7-91 (S-1.1N; 23.8W): Medium-gray, slightly rusty weathering, small-grained, plagioclase-garnet-muscovite-biotite-quartz schist. Most plagioclase is in coarse grains, some as round grains as much as 1 inch diameter, but more commonly in tapered ovoid shapes. Sericite streaks, some of which contain a core of fine-grained sillimanite, separate stringers of quartz, and flow around the feldspar knots and coarse garnet grains. Quartz shows undulose extinction and is moderately sutured. Biotite is moderate yellow brown (10YR 5/4). Grain size is variable.

S1-146 (S-22.3N; 3.6W): Medium-gray, small-grained, slightly rusty-weathering, garnet-biotite-quartz-staurolite-muscovite schist. Foliation is primarily a mica schistosity. Quartz stringers are mostly parallel to the schistosity but may cross it at a low angle. Staurolite and kyanite are surrounded by fine-grained muscovite and sericite. Most biotite is altered to chlorite. Quartz grains in the quartz stringers are about 0.5 mm and strongly sutured; elsewhere quartz is fine grained. Average grain size is about 0.3 mm, but grains are quite variable.

S7-57 (S-1.6N; 22.8W): Dark-gray, medium-grained quartz-epidote-plagioclase-hornblende gneiss (amphibolite). Thin feldspathic laminae separate thicker hornblende rich layers. Epidote is yellowish gray and is colorless in thin section. Minerals are fairly even grained and granular, with an average size of about 1 mm. Hornblende is Y, dusky yellow green (5GY 5/2) and Z grayish green (5G 5/2).

Brimfield Schist

The Brimfield Schist underlies the extreme northwest corner of the Hampton quadrangle, although no exposures of the unit were observed in the area. It is exposed, however, in road cuts a few hundred feet north of the quadrangle boundary, and in natural exposures about 2,000 feet west of the quadrangle. In both localities the strike of the rocks is northeast, toward the corner of the Hampton quadrangle. The Brimfield of this area is continuous with the Brimfield Schist of Emerson (1898, 1917) in Massachusetts and with the Brimfield Schist as redefined by Callaghan (1931). On the basis of regional correlations the Brimfield Schist in the Hampton quadrangle is thought to be equivalent to the Tatnic Hill Formation in the southeast corner of the quadrangle, and is, therefore, overturned.

The Brimfield Schist in the areas north and west of the Hampton quadrangle is a slightly rusty weathering, medium-grained, dark-gray muscovite-biotite-plagioclase-quartz schist. The exposures are about half schist and half pegmatite, and apparently pegmatitic dikes and sills are abundant in this part of the Brimfield. Interlayered calc-silicate rock is also common in this part of the Brimfield (M. Pease, written communication, 1967). In general the Brimfield Schist is typified by strongly rusty weathering schists and gneisses, although reconnaissance in the area northwest of the Hampton quadrangle indicates some nonrusty rocks occur in the unit which are indistinguishable from some rocks of the Tatnic Hill Formation. The main differences between the lithologies of the Brimfield and the Tatnic Hill appear to be the more extensive rusty weathering character of the Brimfield, and more abundant interlayering of calc-silicate rocks.

Hebron Formation

The Hebron Formation is one of the most extensive units in eastern Connecticut, covering a large part of the area from the Monson anticline to the Willimantic dome (see pl. 1, fig. 2). It was named Hebron Gneiss by Gregory (in Rice and Gregory, 1906), for exposures in the town of Hebron, although the typical rocks he mentions (1906, p. 141) are in Moodus and Coventry. Snyder (1961) changed the name to Hebron Formation. The type area for the Hebron is several miles west of the Plainfield-Danielson area, on the west side of the Willimantic dome, and rocks of this area are continuous with those in the type area around the north and south sides of the dome. The Hebron west of the Eastford Gneiss in the northwest corner of the Hampton quadrangle (pl. 3) is the only Hebron in the Plainfield-Danielson area which was shown on most earlier maps, although Percival (1842) recognized some Hebron (his unit E_1) between the rocks of the Putnam Group (his Unit F) and the Scotland Schist (his unit E_6).

The Hebron Formation occurs in several belts which are separated by either the Scotland Schist or the Canterbury Gneiss. The narrow belt of Hebron east of the Canterbury Gneiss across the Scotland and Hampton quadrangles is continuous with the belt west of the gneiss around the northern termination of Canterbury in the Danielson quadrangle (pl. 2). The central belt of Hebron between the Canterbury Gneiss and the Scotland Schist is continuous with the western one, which separates two belts of Scotland, in the central part of the Hampton quadrangle, where Scotland is eroded away. The Hebron west of the Eastford Gneiss in the Hampton quadrangle is also continuous with the one on the east around the northern end of the Eastford north of this area (see pl. 1). The various belts of

Hebron have a general north-northeast strike and a moderate to shallow dip northwest; in the central part of the Hampton quadrangle the dip is about horizontal.

The Hebron Formation is composed primarily of fine-grained calc-siliate schists which are nonresistant to erosion, and most of the unit underlies a general lowland with few exposures. In the Plainfield-Danielson area most exposures are small ones near the base of hills held up by Scotland Schist or Canterbury Gneiss, or are in stream beds; most large exposures of the unit are artificial. The contact between the Hebron Formation and the Yantic Member of the Tatnic Hill Formation is commonly on a dip slope and is poorly exposed. The only observed exposure of the contact is on the west side of Wolf Den Brook in the Danielson quadrangle (D-33.9N; 26.5W), but the contact here is a fault, and the rocks on either side are strongly granulated. Snyder (1961, 1964a) states that the Hebron and Yantic contact is sharp, and it probably is; interlayering of the two rock types has not been observed near the contact, although exposures of either rock near the contact are uncommon. The rather uniform thickness of the underlying Yantic Member suggests that the contact is a conformable one. The Hebron in this area has an apparent thickness of 500 to 1,000 feet. The thickness is, however, difficult to determine, as the Hebron is cut by the Canterbury Gneiss, and an uninterrupted area of the unit from the Yantic Member at the base to the Scotland Schist at the top does not occur in this area. In addition the unit is strongly folded internally, and every large exposure shows a series of isoclinal folds.

Most of the Hebron Formation in the Plainfield-Danielson area is in the staurolite-kyanite grade of metamorphism; staurolite and kyanite occur in the Yantic Member below it and in the Scotland Schist above it. In the northwestern part of the Scotland quadrangle (pl. 5) and the southwestern part of the Hampton quadrangle (pl. 3), however, the schists above and below the Hebron carry sillimanite, and the intervening Hebron there is also sillimanite grade. No specific difference was noted in the mineral assemblages in the rocks of the unit between the two metamorphic grades, but sillimanite grade Hebron is slightly coarser grained than is staurolite grade Hebron.

The axial plane of the Hampton syncline traces through the central part of the Hampton quadrangle, and in part through the Hebron Formation (fig. 1; pl. 3). The Hebron south and east of the trace, which is most of the unit in the Plainfield-Danielson area, is in the normal, or right-side-up limb, and that north and west of the trace is in the overturned limb. There are some lithologic differences between the rocks of the two limbs; the basic rock types are the same, but the relative abundance of different rock types varies.

The rocks of the Hebron Formation are well-layered, medium-gray, greenish-gray, and purplish-gray, fine- to small-grained calc-silicate schists and biotite granular schists. In general the rocks of the normal limb of the Hampton syncline are predominantly calc-silicate schists with less abundant interlayered biotite schist, while those in the overturned limb are mainly biotite granular schist with minor calc-silicate schist. Preliminary mapping in the Putnam quadrangle, however, indicates that in places calc-silicate rocks are also common in the overturned limb. In the northern part of the Hampton quadrangle (pl. 3) the Hebron contains thin lenses of a strongly rusty weathering graphitic muscovite schist. The lenses are probably no more than 20 or 30 feet thick, and can be traced for a mile or two through discontinuous exposure and float concentrations.

They apparently occur near the top of the Hebron, and in both the normal and overturned limb of the syncline. A white, small-grained quartzite is exposed above Waldo Brook in the Scotland quadrangle (S-16.3N; 23.8W), and is overlain and underlain by Hebron. It is about 10 feet thick and can be traced for only about 1/4 mile along strike. It may be interlayered with the Hebron, or it may be in the trough of a small syncline, and be equivalent to the quartzite at Franklin which Snyder (1964a and b) shows locally at the contact of the Hebron Formation and the Scotland Schist.

The rocks of the Hebron Formation are in thin layers, an inch to several inches in thickness. The layers are commonly uniform for several feet along strike and are sharply bounded on either side. In most rocks the layering is parallel to the schistosity, which is formed by the planar orientation of the biotite flakes, and actinolite laths. Many rocks also contain a fine scale lamination of discontinuous stripes of biotite, actinolite or plagioclase, which is also parallel to the schistosity. In most of the unit the rocks are noncataclastic, but locally they are mortar gneisses or mylonites.

Modal analyses of the Hebron Formation are given in table 11. Samples H1-24, H1-36 and H0-92 occur in the overturned limb of the Hampton syncline and the rest are in the normal limb. The most common rock in the unit is biotite-quartz-plagioclase schist (table 11, S8-181, H1-36, H0-92) which may contain calcite (table 11, H9-84, H0-42) actinolite (table 11, H1-24) or both (table 11, S8-168, S8-21). There is a wide variation in the proportions of the constituent minerals. In general quartz and plagioclase together make up 65 percent to 80 percent of the rock. Plagioclase ranges from 10 to 55 percent and is commonly about 35 percent; quartz ranges from 10 to 65 percent and is commonly about 30 percent. Biotite constitutes 2 to 20 percent of the rocks which contain actinolite, and 10 to 50 percent, commonly about 20 percent, of the rocks which do not contain actinolite. Calcite may constitute as much as 15 percent of the rock and is less than 10 percent in most; actinolite is as much as 30 percent and commonly is less than 20 percent. Epidote is a common accessory mineral and locally is as much as 20 percent of the rock; it is more commonly abundant in the actinolite bearing schists than in those without actinolite. Scapolite is rare, but locally may constitute 10 percent of the rock. Muscovite also is rare, but may occur locally; it was not observed in actinolite bearing rocks. Potassium feldspar also may be present locally, but is abundant only in rocks close to pegmatites. Accessory minerals, in addition to epidote, include sphene, apatite, opaque minerals, zircon, allanite, tourmaline and locally garnet.

Less abundant interlayered rock types are actinolite-quartz-plagioclase schists with minor or no biotite. The majority of these are generally similar to the biotite schists, and have about the same range in the proportion of the constituent minerals, although epidote is more commonly abundant, and may be as much as 30 percent of the rock (table 11, HO-51). Less commonly these rocks may contain either or both scapolite and diopside, and either may constitute as much as 25 percent of the rocks, although diopside is commonly less than 10 percent (table 11, H9-76). The scapolite-diopside rocks may or may not contain calcite, most contain 2 to 10 percent epidote, and most contain no biotite, although one sample examined has about 10 percent biotite. Plagioclase is present in the scapolite bearing rocks, though is less abundant than in the nonscapolitic rocks.

The rock in the lenses of muscovite schist in the northern part of the Hampton quadrangle is grayish-orange, olive-gray to dark-gray, small- to fine-grained graphitic plagioclase-biotite-muscovite-quartz schist (table 11, HO-43). The schist commonly contains minor garnet and sericitized staurolite or kyanite. In the railroad cut in central Hampton, from which sample HO-43 was collected, pyrite nodules, in ovoid shapes about an inch long, occur on a joint surface. The nodules are weathered out and are mostly hollow, and apparently the limonite stain in the rocks is from the weathered pyrite. A characteristic feature of the muscovite schist is coarse knots of quartz and kyanite with minor graphite. These were observed in the schist in the railroad cut, and as common float boulders through the area of Catden Swamp north of the railroad cut. The knots are as much as a foot in diameter and kyanite blades are several inches long. In an isolated outcrop the muscovite schist is difficult to distinguish from some of the Scotland Schist.

The quartzite lens in Waldo Brook in the Scotland quadrangle is a white, medium-grained quartzite containing almost 100 percent quartz, and only a few scattered grains of biotite, muscovite and epidote. The grains average about 2 mm diameter. The small amount of quartzite exposed in this area is massive and unlayered.

The rocks of the Hebron Formation most commonly contain even-grained, granular minerals with an average grain size of about 0.1 to 0.3 mm but may be 0.5 mm locally. The quartz grains are generally about equant in dimensions, and show little or no undulose extinction or suturing. The composition of the plagioclase commonly ranges from An 35 to An 50, but locally may be as calcic as An 65. The plagioclase grains are of the same order of size as quartz grains, and where untwinned the plagioclase is difficult to distinguish from quartz. The most common amphibole is a green actinolite in which Y and Z are dusky yellow green (5GY). It occurs in elongate grains slightly longer than the average size of the quartz and plagioclase. In some rocks it is poikilitic, with numerous quartz inclusions. A colorless or very-pale-green actinolite occurs in minor amounts in many of the rocks, commonly as blades along or near the edges of the green actinolite. The two actinolites were separated from one sample (HO-51) and the optical properties are given in table 10. The properties indicate both amphiboles are actinolite; the green actinolite has a Mg/Fe ratio of about 32/68, and the colorless one has a Mg/Fe ratio of about 75/25 (Tröger, 1956). Biotite occurs in fine to small plates commonly slightly longer than the quartz and plagioclase grains. The color of the Z direction is commonly light brown (5YR) to moderate yellow brown (10YR). Epidote is colorless and in most rocks has a low birefringence and anomalous interference colors, although in a few rocks it has a high birefringence. It is commonly in irregularly shapes grains, and may contain fine vermicular inclusions of an unidentified mineral, which may be quartz. Locally it is euhedral. The optical properties of the epidote in sample HO-51 are also given in table 10, and indicate a ratio of Al/Fe^{+++} of 88/12. Scapolite, where present, is commonly in fine to small, irregular grains. Plagioclase adjacent to the scapolite is sharply zoned. Most of the rocks of the Hebron are fresh, and show little or no alteration. Minor chlorite after biotite may be present, and minor plagioclase is sericitized. Locally the rocks are strongly altered and consist of quartz, sericite and chlorite with minor plagioclase.

The rocks of the Hebron are locally cataclastic mortar gneisses or mylonites. The mortar gneisses contain streaks of fine- to very-fine-grained quartz, plagioclase and biotite separated by streaks of normal sized grains.

Table 10.--Optical properties of two amphiboles and epidote from sample HO-51, Hebron Formation.

	Green Actinolite	Colorless Actinolite	Epidote
α	1.662 ± .002	1.627 ± .002	1.715 ± .002
β	1.674	1.640	1.719
γ	1.680	1.650	1.724
δ	0.018	0.023	0.009
$Z \Lambda c$	13°	15°	
$2V_x$	77°	82°	87°
		Composition (From Tröger, 1956)	
	$Ca_2(Mg_{.32}Fe_{.68})_5Si_8O_{22}(OH)_2$	$Ca_2(Mg_{.75}Fe_{.25})_5Si_8O_{22}(OH)_2$	$Ca_2(Al_{.88}Fe_{.12})_3Si_3O_{12}(OH)$

In these rocks quartz is weakly sutured, and in the granulated streaks may be strongly sutured. The mylonitic rocks are very-fine-grained rocks in which the fine biotite forms a strongly oriented network for the rest of the minerals. Locally the rock is a small-grained breccia in which clasts of fine-grained, granulated biotite-quartz-plagioclase schist occur in a very-fine-grained, clayey matrix, which constitutes 25 to 50 percent of the rock. These occur in the northwest corner of the Hampton quadrangle and the southern part of the Eastford quadrangle, and are associated with ultramylonite dikes.

Age and correlation

The age of the Hebron Formation within the Plainfield-Danielson area can be established only as younger than the Tatnic Hill Formation and older than the Scotland Schist. South of this area, in the Fitchville and Willimantic quadrangles (Snyder, 1964a and b), a clean, white quartzite, called the quartzite at Franklin, separates the Hebron and the overlying Scotland Schist. Local cross-bedding in the quartzite indicates that the Scotland is on top of and younger than the Hebron. There are various possibilities for correlation of the Hebron with other units in New England, but none of them can be established as yet. Because of the correlation of the Tatnic Hill Formation and the Brimfield Schist, Hebron is also considered to be younger than Brimfield. The possible age of the Hebron ranges from middle Ordovician to lower Devonian. Incomplete radiometric age determinations in eastern Connecticut suggest the age may be toward the older limit of the range rather than toward the younger, and may be pre-Silurian.

In stratigraphic position above the Brimfield and Tatnic Hill Formations, and in general lithology the Hebron Formation is similar to

The Fitch Formation of the Bolton Group of Rodgers et al (1959), along the western edge of eastern Connecticut (see table 1) The Fitch Formation of Connecticut can be traced intermittently into the middle Silurian Fitch Formation of New Hampshire (Eaton and Rosenfeld, 1960; Billings, 1956). The quartzite at Franklin is, however, similar to the Clough Formation of the Bolton Group and of New Hampshire, of lower Silurian age (Boucot and Thompson, 1963). North of the Plainfield-Danielson area, Hebron traces into Massachusetts into both the Oakdale Quartzite and the Paxton Quartz Schist of Emerson (1917). At least some Oakdale and Paxton are equivalent to rocks of the Merrimack Group in southeastern New Hampshire, which Billings (1956, p. 103) traces into the Waterville Formation in Maine, dated as upper Silurian (Osberg, 1967). Thus, by correlation either with the Fitch Formation or the Waterville Formation, Hebron would be middle to upper Silurian. If, on the other hand the quartzite at Franklin correlates with the Clough Formation, Hebron must be pre-Silurian. The Hebron has not yet been traced by mapping into rocks known to be Fitch or Waterville equivalents, although the latter may be possible with further mapping in Massachusetts.

The Hebron Formation is cut by the Canterbury Gneiss and, in the Columbia quadrangle, (Snyder, 1967) by a quartz monzonite dike, both of which have been dated radiometrically by the whole rock rubidium-strontium method (Zartman et al, 1965). The age obtained for both rocks was 430 ± 20 m.y.[1/]. If this number represents the time of intrusion of the

---

1/ The numbers reported by Zartman and others (1965) were 405 ± 20 m.y., and were based on a decay constant of + 1.47 X $10^{-11} yr^{-1}$. Zartman (personal communication, 1966) would now prefer to use a decay constant of 1.39 X $10^{-11}yr^{-1}$, and would recalculate the numbers accordingly. The numbers used here are, therefore, based on the latter decay constant and differ from the published numbers.

Canterbury sill and the quartz monzonite dike, the Hebron Formation must be older than 430 ± 20 m.y. By either the Holmes (1960) time scale (which puts the Silurian-Ordovician boundary at 440 m.y.) or the Kulp (1961) time scale (which puts the boundary at 425 m.y.), this would indicate lower Silurian or older, and probably a pre-Silurian age for the Hebron Formation.

Origin and chemi~~stry~~ cal composition

The Hebron Formation consists of a metamorphosed sequence of primarily limey rocks. The protolith for the unit was probably a thinly layered sequence of limey, possibly in part dolomitic, siltstones with lesser amounts of non-limey siltstones. In the rocks of the overturned limb of the Hampton syncline the non-limey siltstones predominated, at least locally. A facies change between the limey and non-limey rocks must take place west and possibly north of the Plainfield-Danielson area.

Chemical analyses of two samples of Hebron Formation are given in table 20. In calculating the mesonorms, an aluminous hornblende was calculated rather than nonaluminous actinolite for more ready comparison with the analyses of the Fly Pond Member, although the amphibole in the Hebron is apparently a nonaluminous one. The small amount of excess C in the mesonorms of the Hebron is probably accommodated as excess Al in the micas. The A:C:F ratios of the Hebron samples are plotted on the triangular diagram in figure 5, along with the Hebron analyses from Snyder (1964a). The Hebron ratios overlap the fields of the micaceous pelitic rocks of the Tatnic Hill Formation and the Scotland Schist and of the calc-silicate rocks of the Fly Pond Member of the Tatnic Hill Formation.

Analysis 15 (sample S8-181) in table 20 is about comparable to an analysis of a sample of Fitch Formation given by Billings and Wilson (1964, table 1, no. 6), described as a dolomite slate in the chlorite zone of metamorphism. Other Fitch analyses, however, are considerably richer in CaO and poorer in Al_2O_3 than are any of the Hebron analyses.

Table 11.--Modal analyses of the Hebron Formation.

	S8-21	S8-168 *	HO-51	H9-76	S8-181 *	H9-84	HO-42	H1-24	H1-36	HO-92	HO-43
Quartz.............	22	30	32	35	36	40	37	44	35	25	41
Plagioclase.........	44	35	21	6	15	24	29	25	42	34	10
Biotite............	9	18	x[3/]		46	24	30	4	20	38	15
Muscovite...........							0.4		1		22
Garnet.............							2				x
Actinolite-green....	16	13	10	8				18		x	
Actinolite-colorless			9	5							
Calcite............	7	1		4		9	0.6				
Epidote............			26	10			0.1	7			
Diopside...........				7							
Scapolite..........			0.3	23							
Sphene.............	0.7	0.7	2	2				2	0.5	0.6	
Opaque minerals.....	0.4	0.7	0.5	0.5	2	1	0.6	0.6	0.4	0.2	5[4/]
Zircon.............	x	0.3	x	x	0.2	0.1	0.2	x	x	0.4	x
Apatite............	x	0.5	0.3	x	0.2	0.4	0.1	0.1	0.4	0.1	x
Tourmaline.........	x	x		x	x	0.1	0.2				0.3
Allanite...........										0.1	
Chlorite[1/]..........	x(b)	0.5(b,a)				0.7(b)	0.2(b)				x(b,g)
Sericite[2/]..........						0.6(p)	0.6(p)				5(s)
Limonite...........					0.5			0.1		2	2
Comp. of Plag.......	An45	An38	An45	An40	An40	An38	An30	An65	An32	An40	An35

Percentages rounded off to the nearest whole number, except those of less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.

* Samples of which chemical analyses are reported in table 20.

1/ Chlorite from (b) biotite, (a) actinolite, (g) garnet.

2/ Sericite from (p) plagioclase, (s) staurolite.

3/ No biotite in thin section, but crushed rock contains minor biotite.

4/ Opaque is mostly graphite.

Hebron Formation:

S8-21 (S-16.5N; 23.7W): Medium-light-gray, fine-grained calcite-biotite-actinolite-plagioclase-quartz granular schist. Foliation is defined by planar orientation of biotite flakes, and by fine-scale, discontinuous laminae of amphibole and of quartz and feldspar. A diffuse layering is parallel to the foliation, and represents a small difference in abundance of mafic versus felsic minerals. A thin (1 mm) band of quartz and calcite is also parallel to the foliation, and outlines a small, isoclinal fold. The rock is granular with even grained quartz and plagioclase. Quartz is not sutured. Biotite and actinolite grains are slightly longer than the quartz and plagioclase. Biotite is moderate yellow orange (10YR 5/4). Actinolite is Y, grayish green (10GY 5/2) and Z, light blue green (5BG 6/6). Average grain size is about 0.2 mm.

S8-168 (S-16.4N; 23.7W): Medium-gray, fine-grained actinolite-biotite-quartz-plagioclase granular schist. Foliation and lamination are as in S8-21. Quartz and plagioclase are in even, granular, grains; quartz is not sutured. Biotite is light brown (5YR 5/6). Y and Z of actinolite are dusky yellow green (5GY 5/2). Average grain size is about 0.2 mm.

HO-51 (H-14.2N; 21.5W): Greenish-gray, small-grained actinolite-epidote-plagioclase-quartz gneiss. Foliation is defined by a diffuse composition layering parallel to a cleavage plane. A minor amount of biotite can be seen on the weathered surface, but none was included in the thin section. Epidote is in irregular grains with a low birefringence, anomalous interference colors, and contains vermicular inclusions of an unidentified mineral, possibly quartz.

The minor scapolite is associated with, and apparently replaces plagioclase. Quartz grains are weakly sutured. The green actinolite is Y and Z dusky yellow green (5GY 5/2). Average grain size is about 0.3 mm.

H9-76 (H-6.1N; 15.5W): Medium-light-gray, and greenish-gray, small-grained calcite-epidote-diopside-actinolite-scapolite-quartz gneiss. A greenish-gray layer 1/2 inch thick, is at an angle to the foliation as defined by orientation of tabular amphibole grains in the light-gray layers on either side. The layer has diffuse boundaries. Most diopside of the rock is in the greenish layer and most actinolite is in the gray layer. Plagioclase and scapolite are indistinguishable megascopically. In thin section the minor plagioclase is associated with scapolite and is strongly zoned; scapolite apparently has replaced plagioclase. Amphibole is greenish black; diopside is pale yellowish green. Minor biotite occurs in the hand sample, but none was included in the thin section. Epidote has a low birefringence, anomalous interference colors and some grains are euhedral. Diopside forms euhedral to anhedral grains as much as 1 mm diameter. Very-fine-grained actinolite overgrowths are perpendicular to the edges of diopside grains, and give the appearance of a sawtooth edge; some of the actinolite is bladed and some occurs as diamond shaped euhedra. Rock contains both colorless and green actinolite; the green actinolite is Y and Z dusky yellow green (5GY 5/2). Average grain size is about 0.2 mm.

S8-181 (S-6.4N; 32.5W): Light-olive-gray, slightly rusty weathering, fine-grained, plagioclase-quartz-biotite granular schist. Foliation is defined by planar orientation of the biotite flakes, and by a fine scale layering reflecting differences in the concentration of biotite. Biotite is bleached to golden brown on the weathered surface. Quartz and plagioclase are granular with an average size of about 0.2 mm; quartz is not sutured. Biotite grains are only slightly longer; biotite is light brown (5YR 5/6).

H9-84 (H-20.3N; 15.5W): Medium-gray, fine-grained calcite-biotite-plagioclase-quartz granular schist. Foliation is defined by planar orientation of the biotite flakes. Quartz, plagioclase and calcite are in even, granular grains with an average size of about 0.2 mm. Quartz is weakly sutured. Biotite is moderate yellow brown (10YR 5/4).

H0-42 (H-26.0N; 16.4W): Medium-dark-gray, fine-grained biotite-plagioclase-quartz granular schist. Foliation is defined by planar orientation of the biotite flakes, and by parallel thin laminae of quartz. The garnet occurs in the quartz laminae as long, (as much as 1 cm) thin (less than 0.5 mm), skeletal, poikilitic grains. Quartz and plagioclase are even, granular grains with an average size of about 0.1 mm. Muscovite and chlorite are interleaved with biotite and both may be secondary after biotite. Biotite is light brown (5YR 5/6).

H1-24 (H-42.3N; 26.7W): Medium-gray, slightly rusty-weathering, fine-grained biotite-epidote-actinolite-plagioclase-quartz granular schist. Foliation is defined by planar orientation of the mica plates and actinolite laths. The rock has even-grained, granular minerals with an average size of about 0.2 mm; actinolite is commonly a little larger. Quartz grains are not sutured, and do not show undulose extinction. Biotite is dark yellow orange (10 YR 6/6).

Acinolite is Y and Z pale olive (10Y 5/2).

H1-36 (H-37.9N; 33.8W): Medium-gray, small-grained biotite-quartz-plagioclase granular schist. Foliation is defined by planar orientation of the biotite flakes. Weathered surface is slightly rusty. Rock has even-grained, granular minerals with an average size of about 0.3 mm. Quartz is not sutured, and does not show undulose extinction. Biotite is light brown (5YR 5/6).

HO-92 (H-25.3N; 21.6W): Medium-dark-gray, slightly rusty-weathering, fine-grained quartz-plagioclase-biotite granular schist. Foliation is defined by planar orientation of the biotite. Streaks of granulated grains are parallel to the biotite foliation. In and near the streaks quartz is strongly sutured; other quartz is weakly sutured and shows undulose extinction. Plagioclase is slightly zoned. Biotite is light brown (5YR 5/6). Grain size is variable with a maximum of about 0.5 mm.

HO-43 (H-25.9N; 16.5W): Olive-gray, moderately rusty-weathering, small-grained plagioclase-biotite-muscovite-quartz schist. Foliation is defined by planar orientation of the micas. Lenses of medium-grained quartz, are bordered by fine-grained quartz, plagioclase and micas. Knots of sericite 1 mm or more in diameter with only minor chlorite are probably after kyanite or staurolite, although none is now left. Garnet is mostly fresh, and where altered it is mainly chlorite. Biotite is light brown (5YR 5/6). The medium-grained quartz averages about 1 mm; the rest of the rock has an average grain size of about 0.1 mm.

Scotland Schist

The Scotland Schist is the youngest of the metasedimentary rocks in the Plainfield-Danielson area, as well as in eastern Connecticut east of the Monson Anticline. The unit was named by Gregory (in Rice and Gregory, 1906) for a "coarse muscovite schist, squeezed into minute folds" which "covers the town of Scotland" (1906, p. 141). He gave no type locality for the unit, and the only outcrop he cited (a railroad cut east of Pautipaug Hill in the southern part of the Scotland quadrangle) is well within the Yantic Member of the Tatnic Hill Formation, and is separated from the Scotland Schist by exposures of the Hebron Formation and of Canterbury Gneiss. The series of road cuts and bluffs north of the Shetucket River in the southwestern corner of the town of Scotland (pl. 5, S-13.4-14.4N; 30.2-32.2W) has been established as the type locality for the Scotland Schist (text accompanying pl. 5).

The Scotland Schist occurs in two generally north trending belts in the Scotland quadrangle (pl. 5). Both belts are shallow, open synclines which plunge out, or are eroded through in the southern and central parts of the Hampton quadrangle (pl. 3). In the northern half of the Hampton quadrangle there are two belts of isoclinally folded Scotland, in the core of the recumbent Hampton syncline. The schist is apparently squeezed out of the core in the center of the quadrangle between the two belts. The Scotland Schist in the southern half of the Hampton quadrangle and the Scotland quadrangle is, therefore, in the normal limb of the Hampton syncline, and the open synclines are warps in the normal limb. The Scotland Schist continues south of the Scotland quadrangle through the Willimantic and Fitchville quadrangles (Snyder, 1964a and b) to just north of the Honey Hill fault (pl. 1). North of the Danielson quadrangle it apparently continues as a narrow belt in the core of the recumbent syncline into Massachusetts.

The Scotland Schist is primarily a coarse muscovite schist which is resistant to erosion and the unit commonly forms a topographic high. The top of the unit is not exposed, and it apparently has a maximum thickness in the southern part of the Scotland quadrangle and in the Willimantic quadrangle, where the maximum apparent thickness is about 800 feet. The contact with the underlying Hebron Formation is fairly well exposed on the lower slopes of hills held up by more resistant Scotland Formation. The contact is fairly sharp and appears to be conformable. A narrow zone of gradation, commonly less than a foot thick can be seen locally between the two units. The base of the Scotland is commonly a biotite-plagioclase-quartz schist which in places is difficult to distinguish from similar rocks in the Hebron. The contact is marked, however, by the absence of calc-silicate rocks and the presence of associated muscovitic rocks above it. Thin beds of quartzite, no more than a few inches thick, occur locally just above the contact. The quartzite possibly grades laterally into the coarse, white quartzite at Franklin that separates the Scotland from the Hebron Formation in parts of the Fitchville and Willimantic quadrangles (Snyder, 1964a and b). A few primary sedimentary bedding features in the Scotland Schist near the base of the unit, and in the quartzite at Franklin indicate that the Scotland Schist is on top of, and younger than the Hebron Formation.

The basal 5 to 25 feet of the Scotland Schist consist of alternating fine-grained, granular schist and coarse-mica schist. Individual layers range in thickness from an inch to about a foot; in general layers of granular schist are thicker and more abundant than the coarse-mica schist.

In this zone the layering appears to be primary bedding and the quartz and plagioclase rich, granular schist commonly grades upward into micaceous schist. The rest of the Scotland is a fairly massive coarse-muscovite schist, with indistinct layering. A thin strongly folded, fine-grained quartzite layer, about 10 feet thick occurs about 600 feet above the base of the Scotland in the southwestern part of the Scotland quadrangle. North of that area the Scotland is apparently not thick enough to include the quartzite.

The Scotland Schist is commonly a dark-gray schist which is either nonrusty or very slightly rusty weathering. The rusty weathering in general is more prominent in the northern part of the Plainfield-Danielson area, and in an isolated outcrop in the north the schist may be difficult to distinguish from some Brimfield Schist. The unit typically contains small quartz lenses about an inch thick and three or four inches long. The lenses are commonly stained grayish orange. The weathered surface of the Scotland Schist typically shows small, weathered out crystals (a few millimeters in size) of red garnet, staurolite and locally kyanite and tourmaline. Rare, thin lenses, an inch or two in thickness, of greenish calc-silicate rock are interlayered with the muscovite schist. The foliation of the Scotland Schist is primarily a mica schistosity which, in the lower part of the unit, is commonly parallel to the layering. In the massive, coarse-mica schist some of the rocks show a strong schistosity while others show a strong crinkle lineation in the muscovite plates but a diverse orientation of the micas, and no well developed foliation. Most of the Scotland is not cataclastic, although rocks which contain streaks of granulated minerals are fairly common.

Modal analyses of several samples of Scotland Schist are given in table 12. The granular schist in the lower part of the unit is commonly a dark-gray, fine-grained muscovite-biotite-plagioclase-quartz schist, commonly containing minor garnet, but rarely with staurolite or kyanite (table 12, S8-35, H0-99). Quartz makes up 10 to 60 percent of the rock, and commonly about 45 percent; plagioclase is 10 to 40 percent and commonly 25 percent; biotite is 5 to 30 percent and commonly about 25 percent; and muscovite is 0 to 20 percent. In most of the granular schist muscovite is less abundant than biotite, but in some rocks it may be more abundant. Garnet is rarely more than 1 or 2 percent of the granular schist. In the coarse mica schists interlayered with the granular schist near the base, and forming most of the unit above the basal zone the common rock is a dark-gray, fine-grained plagioclase-biotite-muscovite-quartz schist with coarse mica plates. Most of the schist contains garnet (table 12, S8-185, S7-138, S7-106), it commonly contains staurolite (table 12, S8-60, S7-128) and locally contains kyanite (table 12, H0-117, H9-80). Quartz and muscovite together make up 60 to 80 percent of most rocks; biotite is commonly 10 to 15 percent, and plagioclase is less than 10 percent. Garnet and staurolite are less than 5 percent of most rock but either may be as much as 20 percent. Kyanite, where present, is rarely more than 5 percent. Graphite is a common accessory mineral, and in many rocks it occurs mainly as inclusions in garnet and staurolite. Other accessory minerals are tourmaline, apatite and zircon.

The quartzite in the southern part of the Scotland quadrangle is a buff to medium-gray, fine-grained quartzite with 85 to 95 percent quartz and minor amounts of plagioclase, muscovite, biotite and garnet (table 12, S7-137). The local layers of quartzite at the base of the unit are generally similar in composition.

The rocks of the Scotland Schist are fine-grained, granular to coarse-mica schists in which the quartz and plagioclase have an average grain size of 0.1 to 0.3 mm. Quartz is most commonly in even grains which are not sutured and do not show undulose extinction, although in rocks which contain somewhat coarser grained quartz, it may show moderate undulose extinction. Plagioclase is commonly in fine, even grains; the composition is An 20 to An 30. The fine-grained plagioclase of some rocks is poorly twinned and is difficult to distinguish from quartz. Muscovite is the most prominent mineral of the coarse-mica schist, and occurs in plates 2 or 3 mm in diameter which are commonly strongly crinkled. Biotite is commonly in smaller grains, about the same size as or slightly longer than the average quartz and plagioclase grains. The Z direction of biotite is commonly moderate yellow brown (10YR) to light brown (5YR). Garnet is dark red megascopically and is colorless in thin section. It is commonly in subhedral to euhedral grains 1 to 2 mm in diameter. In some rocks the garnet is poikilitic, and skeletal to euhedral in outline; the inclusions are mainly quartz, biotite and graphite. None of the garnets showed evidence of rolling. Staurolite is the principal aluminum silicate mineral in the most of the area, but from the central part of the Scotland quadrangle north, minor amounts of kyanite are commonly associated with the staurolite. In the belt of Scotland Schist along the western edge of the Hampton quadrangle kyanite occurs without associated staurolite. Andalusite was reported by Foye (1949, p. 78) from the Scotland Schist above the power plant north of the Shetucket River in the southwestern part of the Scotland quadrangle, but examination of Foye's thin sections indicated staurolite but no andalusite in the rocks. The staurolite is commonly in cross-twinned grains several millimeters long. The kyanite in most rocks is in fine grains less than 0.5 mm long, but locally forms blades several millimeters long which stand out on the weathered surface. Both minerals are subhedral to euhedral in thin section, and may be poikilitic with numerous inclusions of quartz, and staurolite commonly contains graphite inclusions. Staurolite is fresh to completely sericitized. Other alteration of the rocks is minor, but locally biotite is altered to chlorite, plagioclase to sericite, and the rusty stained rocks commonly contain limonite.

Age and correlation

Within the Plainfield-Danielson area the age of the Scotland Schist can be established only as younger than the Hebron Formation, and it is probably middle Ordovician to lower Devonian in age. One possible correlation of the Scotland Schist is with the Littleton Formation of the Bolton Group of Rodgers et al (1959) along the western edge of eastern Connecticut. The Littleton Formation in Connecticut has been traced by Peper (1967) and Robinson (1967) northward across Massachusetts and into the Littleton Formation in New Hampshire, although not quite continuously. The Littleton Formation in New Hampshire is dated by fossils (Boucot and Arndt, 1960) as lower Devonian. The Scotland Schist cannot, however, be traced into the Littleton Formation in Connecticut (see pl. 1), and correlative units to the north, across the central part of eastern Massachusetts and into New Hampshire, are not well established. The correlation of the Scotland Schist and the Worcester Phyllite of Massachusetts has been suggested (Snyder, 1961; Zartman et al, 1965), and north of the Plainfield-Danielson area the Scotland does trace into one belt of Worcester Phyllite as mapped by Emerson (1917). It is unlikely, however, that the Scotland Schist is correlative with the Worcester Phyllite at the coal mine in Worcester where the Carboniferous fossils have been found (White, 1912; see also Zartman et al, 1965).

Origin and chemi~~stry~~cal Composition

The rocks at the base of the Scotland Schist consist of metamorphosed interlayered shales and siltstones. At the contact with the Hebron Formation some fairly pure quartz sandstone was deposited, but it must have been thin and of limited lateral extent. Above the basal zone the unit was mostly shale with only minor interlayered siltstone and sandstone.

Chemical analyses of the Scotland Schist are given in table 20 (analyses 8 to 11). The mesonorms are in general comparable to the modal analyses of table 12, but the normative plagioclase is somewhat higher than the modal plagioclase. As in the Tatnic Hill Formation, samples in which normative C (excess Al_2O_3) is greater than 5 contain aluminum-silicate minerals; where C is less than 5, the excess Al_2O_3 is in garnet and probably as an excess in the micas. The A:C:F: ratios of the Scotland samples listed in table 20, and of the samples listed by Snyder (1964a, table 4) from the Fitchville quadrangle are shown in figure 5. Most of the Scotland ratios cluster in a restricted area of high A and low C as compared with the gneisses of the Tatnic Hill Formation. One sample from the Fitchville quadrangle is well outside the cluster of the rest of the Scotland, and is higher in C and lower in Al; the sample contains more modal plagioclase than is common in the Scotland Schist.

Chemical analyses of the Scotland Schist are generally similar to analyses of shales listed by Hill and others (1967, table 2). Analyses 8 and 9 (table 20) are also closely comparable to analyses of the Littleton Formation given by Shaw (1965, table 2); analyses 10 and 11 are, however, somewhat richer in SiO_2 than any analysed Littleton (see also Billings and Wilson, 1964). The averages of the Scotland Schist analyses show some of the same anomalous chemical characteristics as the Littleton. Shaw (1956, p. 934) concludes that in comparison with the average pelitic rock, the Littleton Formation is deficient in CaO, Na_2O, and CO_2, and contains more Al_2O_3 and TiO_2. The average of the 4 analyses of Scotland listed in table 20, and of 3 analyses of Scotland listed by Snyder (1964a, table 4, no. 8, 9 and 11; analysis no. 10 was not included as the location from which the sample was collected is within the Hebron Formation on the geologic map) suggest that the Scotland shows the same deficiency of CaO, Na_2O and CO_2 as does the Littleton. The average CaO of the Scotland is 0.53 as compared with 0.52 for the medium and high grade Littleton, Na_2O of Scotland is 1.21 as compared with 1.38 for Littleton, and CO_2 of Scotland is 0.2 compared with 0.3 for Littleton (Shaw, 1956, table 13). The average Al_2O_3 of the Scotland is, however, not only considerably less than the average Littleton, but is less than Shaw's average medium to high grade pelitic rock (Scotland Al_2O_3 average is 16.89; Littleton is 20.64; pelitic rock is 17.35). This difference could be the result of sampling bias. The major variable in the mineral composition of most of the Scotland Schist is the presence or absence of aluminum-silicate minerals, mostly staurolite. Only 3 out of the 7 analysed Scotland samples contain more than 1 percent staurolite, while the Littleton samples listed by Shaw 8 of 11 contained more than 5 percent staurolite or sillimanite (1956, table 4). Probably more careful sampling of the Scotland is needed to determine whether the low Al_2O_3 is characteristic of the unit.

Table 12.--Modal analyses of the Scotland Schist.

	S8-185 *	S7-138 *	S8-35	H0-117	S8-60	S7-128 *	H9-80	H0-99	S7-106 *	S7-137
Quartz...............	61	56	50	50	51	41	36	35	25	91
Plagioclase..........	8	3	28	2	x	3	7	12	1	2
Biotite..............	8	8	17	13	14	7	15	39	18	2
Muscovite............	14	24	.	28	18	22	29	9	28	0.5
Staurolite...........	0.2	0.5			5	8	0.7			
Kyanite..............				4			3			
Garnet...............	4	3	2	1	8	2	1	x3/	1	3
Opaque minerals......	2	24/	24/	24/	14/	54/	14/	1	3	0.5
Apatite..............	x	0.2	x		x		x	0.2		
Zircon...............	x	x	0.2	x	x	x	x	x	x	x
Tourmaline...........	x	0.3		x	0.2	0.2	0.3	x	0.1	x
Chlorite1/...........	2(b,g)	0.7(b)			1(b,g)	5(g,s)	2(b)		0.5(g)	1(b,g)
Sericite2/...........	0.2(s)					x(s)	x(k)		7(s,g)	
Limonite.............	1	3				7	2	4	7	
Comp. of Plag........	An20		An35	An22	An24	An20	An23			

Percentages rounded off to the nearest whole number, except those less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.

* Samples for which chemical analyses are reported in table 20.

1/ Chlorite after (g) garnet, (b) biotite.

2/ Sericite after (s) staurolite, (k) kyanite, (g) garnet.

3/ No garnet in thin section, but is present in hand sample.

4/ Opaque is mainly graphite.

Scotland Schist:

S8-185 (S-42.3N; 24.0W): Medium-light-gray, slightly rusty-weathering, small-grained garnet-biotite-plagioclase-muscovite-quartz schist. Foliation is defined by planar orientation of the micas, and by a diffuse, thin layering of quartz rich and mica rich layers, about 1/4 inch thick. Muscovite plates show a crinkle lineation. Grayish-red euhedral garnet is commonly less than 0.05 inch diameter. Quartz and plagioclase are in even, granular grains with an average size of about 0.5 mm. Quartz shows weak undulose extinction and is not sutured. Biotite is light brown (5YR 5/6).

S7-138 (S-17.5N; 25.7W): Medium-gray, slightly rusty-weathering, small-grained garnet-biotite-muscovite-quartz schist. Mica flakes are oriented along two schistosity planes. In thin section, streaks of granulated minerals are parallel to both directions of mica orientation. Most granulation is of quartz and, less abundantly biotite grains. Quartz grains vary from very-fine-grained to an average of about 0.5 mm. Quartz is moderately sutured and shows moderate undulose extinction. Biotite is light brown (5YR 5/6).

S8-35 (S-16.3N; 25.9W): Medium-gray, slightly rusty-weathering, fine-grained, garnet-biotite-plagioclase-quartz granular schist. Foliation is defined by planar orientation of the fine-grained biotite and by a diffuse layering of biotite rich layers. Quartz and plagioclase are in fine, granular grains which average about 0.2 mm diameter, and biotite flakes are about the same in length. Quartz is not sutured and does not show undulose extinction. Garnet grains are poikilitic, commonly skeletal and as much as 2 mm long. Biotite is moderate yellow brown (10YR 5/4).

HO-117 (H-30.5N; 26.8W): Medium-gray, slightly rusty-weathering, small-grained, garnet-kyanite-biotite-muscovite-quartz schist. Micas are variously oriented, and the sample is strongly lineated but weakly foliated. Quartz rich zones are linear rods, rather than layers, and mica orientation is partly parallel to the rods. Kyanite blades are medium-bluish-gray and are as much as 1/4 inch long. Pale-red garnets are less than 0.1 inch diameter. Quartz is in even, granular grains about 0.5 mm diameter; it is not sutured and shows weak undulose extinction. Muscovite flakes are as much as 2 mm long. Biotite is dark yellow brown (10YR 6/2).

S8-60 (S-13.9N; 31.0W): Medium-dark-gray, small-grained staurolite-garnet-biotite-muscovite-quartz schist. Micas are variously oriented, and rock is weakly foliated and strongly lineated. The lineation is primarily a crinkle, and less obviously a mineral lineation. In thin section about one-third of the micas are oriented in one direction. Garnet is in euhedral grains about 1 mm diameter. Quartz grains are granular with an average size of about 0.3 mm and are weakly sutured. Muscovite flakes are as much as 3 mm long, and may be bent and crinkled. Biotite is light brown (5YR 5/6).

S7-128 (S-7.1N; 34.0W): Medium-dark-gray, slightly rusty-weathering, fine-grained staurolite-biotite-muscovite-quartz schist. A layer of quartz-rich granular schist, about 1/2 inch thick, is bounded on both sides by coarse-mica schist, although on one side a lensed quartz vein occurs between the layers. The mica schistosity is subparallel to the layering, though diverges from it where displaced by the quartz vein. Muscovite plates are strongly crinkled in two directions, about 60° from each other. The thin section includes part of the coarse schist, the quartz vein and the granular schist. The vein consists of medium-grained quartz with local zones, especially along the edges of very-fine-grained quartz; most of the limonite in the rock is in the vein. The granular schist consists of fine-grained, granular quartz with an average size of about 0.2 mm, and fine-grained micas and staurolite in anhedral, irregular grains. The coarse schist contains fine-grained granular quartz, coarse mica plates, especially muscovite and coarse-subhedral to euhedral staurolite. Biotite is light brown (5YR 5/6).

H9-80 (H-15.9N; 16.4W): Medium-gray, slightly rusty-weathering, small-grained, garnet-kyanite-plagioclase-biotite-muscovite-quartz schist. A crinkled foliation plane is defined by the orientation of mica plates and concentration of the micas in streaks which separate discontinuous lenses of quartz and feldspar about 0.1 inch thick. Kyanite is in thin blades as much as 1/2 inch long. Quartz and plagioclase are variable but average about 0.6 mm; quartz is not sutured, and large grains show moderate undulose extinction. Garnet is in euhedral grains about 1 mm diameter. Staurolite occurs as inclusions in muscovite. Mica flakes, especially muscovite may be several millimeters long. Biotite is light brown (5YR 5/6).

H0-99 (H-29.5N; 14.2W): Medium-dark-gray, weathered brownish-gray, fine-grained muscovite-plagioclase-biotite-quartz schist. Sample shows graded bedding, with the biotite-rich portion of a bed grading into biotite poor. Individual beds are as much as 0.3 inch thick. Foliation is defined by the splitting plane of the rock, and is at a high angle to the bedding. Orientation of the biotite flakes is parallel to the bedding plane near the base of an individual bed, and refracted toward parallelism with the foliation plane in the upper, biotite poor, part of the bed. A strong lineation represents the intersection of the bedding and foliation. Quartz and plagioclase are even, fine-grained with an average size of about 0.1 mm; quartz is not sutured. Biotite is light brown (5YR 5/6).

S7-106 (S-6.4N; 32.1W): Medium-dark-gray, moderately rusty-weathering, fine-grained biotite-muscovite-quartz schist. Foliation is defined by planar orientation of the mica plates; muscovite is in coarse crinkled plates several millimeters long. Quartz and the minor plagioclase are in fine, even grains which average 0.1 mm diameter; quartz is not sutured and does not show undulose extinction. Clots of sericite are pseudomorphous after staurolite, though no unaltered staurolite is left within the area of the thin section. Biotite is moderate yellow brown (5YR 5/3).

S7-137 (S-14.5N; 33.0W): Medium-gray, fine-grained quartzite with minor garnet, biotite and plagioclase. Weathered surface is slightly rusty. The rock is not foliated; in thin section the biotite flakes are diversely oriented. Quartz grains average about 0.3 mm diameter and are weakly sutured. Garnet grains are poikilitic, skeletal and elongate. Biotite is moderate yellow brown (5YR 5/4).

METAIGNEOUS ROCKS

The major units of probable igneous intrusive rocks in the Plainfield-Danielson area are the Canterbury Gneiss and the Eastford Gneiss in the upper plate of the Lake Char fault and the Sterling Plutonic Group of the lower plate. The Canterbury and Eastford are pre- or syntectonic gneisses which occur as sills mostly in the Hebron Formation. The Sterling gneisses are probably pretectonic rocks, and in the Plainfield-Danielson area occur as sills in the Plainfield Formation. The Sterling has been separated into the Hope Valley Alaskite Gneiss and the Scituate Granite Gneiss on the Plainfield and Danielson quadrangle maps (pl. 2 and 4), but the separation was based primarily on work outside this area (Feininger, 1965b; G. Moore, personal communication, 1966), as the rocks are of too limited extent and exposure to be adequately separated within the area.

A small gabbro sill is exposed in the Plainfield quadrangle (pl. 4) within the lower member of the Tatnic Hill Formation. The sill is probably satallitic to the Preston Gabbro south of this area (pl. 1; fig. 2). Other probable intrusive rocks in the area are the numerous pegmatite dikes and sills which occur in all rock units. The largest and most densely spaced pegmatites occur in the Fly Pond and Yantic Members of the Tatnic Hill Formation. These are close to the Canterbury Gneiss and may have been residual liquids from the Canterbury; they would, however, have come off the base of the Canterbury sill and pegmatites near the top of the sill are rare and small. Pegmatites in the rest of the area are probably not related to the Canterbury and may be of diverse origin and age. Most pegmatites are foliated parallel to the foliation of the enclosing rocks; a few small ones are unfoliated.

Canterbury Gneiss

The Canterbury Gneiss forms a large tabular sill-like body of light-gray biotite granodiorite which underlies most of the western half of the Plainfield-Danielson area. It was named Canterbury Granite-Gneiss by Gregory (in Rice and Gregory, 1906) for the town of Canterbury in the Scotland quadrangle (pl. 5). Snyder (1961) changed the name to Canterbury Gneiss. The Canterbury occurs primarily in the Hebron Formation, but locally cuts down to the Yantic Member of the Tatnic Hill Formation and apparently up into the Scotland Schist (Snyder, 1964a).

In the Plainfield-Danielson area the Canterbury Gneiss is exposed in two belts which are apparently continous beneath the Scotland Schist and the Hebron Formation to form a large, open syncline. The eastern belt includes the type area of the Canterbury Gneiss and is, in general, similar in outline to its appearance on earlier maps (Foye, 1949; Rodgers et al, 1956), but the western belt was included as a part of the Eastford Gneiss. Mapping in the Hampton quadrangle (pl. 3), however, showed that the Eastford Gneiss in the northern part of the quadrangle and the Canterbury gneiss in the southern part of the quadrangle and are not continuous as shown on the earlier maps, but are separated by Scotland Schist and Hebron Formation. The western belt of Canterbury surrounds the east side of the Willimantic dome, and is apparently pinched out on the north and south sides of the dome (see pl. 1). It does not, however, lens out in the central part of the Hampton quadrangle as shown on the geologic map (pl. 3), but continues southwest as a thin sill within the Hebron Formation into the adjacent Spring Hill (M. Pease, personal communication, 1966) as shown on plate 6.

The Canterbury Gneiss extends south of the Plainfield-Danielson area through the Norwich and Fitchville quadrangles (Snyder, 1961, 1964a) to just north of the Honey Hill fault, and after a break in continuity, it continues southwest above the fault to the Connecticut River (see pl. 1). Preliminary mapping in the Putnam quadrangle indicates that the Canterbury is exposed again north of the village of Putnam and continues north into Massachusetts several miles. Snyder (1967) mapped a large body of Canterbury on the southeast side of the Willimantic dome. The Canterbury sill, thus has a north-south dimension of several tens of miles and a probable east-west dimension of 15 to 20 miles.

The Canterbury Gneiss in the Plainfield-Danielson area has a maximum thickness of about 1,000 feet. It thins considerably in the southern part of the Scotland quadrangle (pl. 5) north of the Shetucket River, but probably does not lens out as shown on the map. More likely the faults which cut the Scotland Schist to the west are continuous to the southeast and offset the thinned Canterbury as indicated on plate 6. The thickness of the sill decreases to the west toward the Willimantic dome.

The contact between Canterbury Gneiss and the enclosing Hebron Formation is poorly exposed, but apparently it is subparallel to the foliation of both rocks and to the layering of the Hebron. The only known exposures of the contact are near the western edge of the Hampton quadrangle where several outcrops include both rocks. The foliation in the Canterbury is parallel to that in the Hebron and the contact between the two cuts the foliation at a low angle. Inclusions of Hebron, as much as a few feet long and one or two feet thick, are common near the edges of the Canterbury. The rocks of the Hebron Formation near the Canterbury show no indication of contact metamorphism, and the distribution of the metamorphic isograds in the area does not relate to proximity to the sill. Most of the

Canterbury is surrounded by staurolite-kyanite grade rocks, although on the western edge of the sill the surrounding rocks are sillimanite grade. Locally the gneiss is fine-grained near the edges of the sill, but this is not common, and in places may be the result of cataclasis rather than a fine-grained border facies.

The common rock of the Canterbury Gneiss is mostly a light-gray, medium-grained, biotite granodiorite gneiss, although it ranges in composition from tonalite to quartz monzonite. The gneiss commonly contains coarse feldspar grains, both microcline and plagioclase, which average about a centimeter in length and 5 mm in width. The foliation is defined primarily by subparallel alignment and orientation of biotite flakes. In some rocks thin quartz and feldspar laminae are parallel to the biotite schistosity, but in most of the gneiss the feldspars are not segregated into laminae. A second plane of biotite alignment and orientation can be seen in many rocks. The prominent foliation is in general parallel to the foliation in the surrounding rocks and to the top and bottom of the sill. The foliation, thus dips gently west on the east side of the sill and gently east on the west side. Clusters of biotite flakes are strung out at the intersection of the two biotite foliation planes to give a strong lineation which is commonly more prominent than either foliation plane. The lineation plunges N. 5° to 15° E. at a low angle, and is locally reversed to a gentle southwest plunge. Thin aplite sills, 1 to 2 inches in thickness are common near the base of the sill. Most of the aplites are parallel to the foliation in the gneiss, though locally they cross it at a low angle.

Modal analyses of the Canterbury Gneiss are given in table 13. The common rock of the unit is a biotite-microcline-quartz-oligoclase gneiss.

Oligoclase ranges from 20 to 60 percent of the rock, and averages 40 percent; quartz ranges from 20 to 40 percent, and averages 30 percent; microcline ranges from 1 to 40 percent, and averages 17 percent; and biotite ranges from 1 to 15 percent, and averages 10 percent. Muscovite may locally constitute as much as 4 percent of the rock, but most rocks contain no or minor muscovite. Epidote is a common accessory mineral and may constitute as much as 3 percent of the rock, although in most rocks it is less than one percent. A minor amount of allanite is commonly associated with the epidote. Other accessory minerals include sphene, apatite, opaque minerals and zircon, and together they amount to less than 1 percent of the rock. Garnet is also present locally in accessory amounts.

The rocks of the Canterbury Gneiss most commonly have an even grained, granular texture. The average grain size varies somewhat, but in most rocks it is about 1 mm. Plagioclase or microcline may occur in coarse grains about 1 cm long and 5 mm wide. The coarse feldspar grains commonly amount to about 10 percent of the feldspar of the rock. Quartz grains are not sutured in most rock, although local zones of granulated grains and fine-grained sutured quartz occur in some rocks. Both plagioclase and microcline commonly contain minor, thin perthitic intergrowths of the other feldspar. The composition of the plagioclase is An 20 to An30, and is close to An 25 in most rocks. Minor myrmekitic plagioclase is adjacent to microcline; less than 5 percent of the plagioclase is myrmekitic. The coarse myrmekite mantles described by Lundgren (1966a, p. 7) in the cataclastic Canterbury to the southwest near the Honey Hill fault do not occur in this area. Plagioclase is not zoned in most rocks, but in some, particularly those which contain prominent granulated streaks, it may be complexly zoned from about An 20 to An 30. The biotite is commonly aligned in two directions; the more prominent direction is parallel to the weak lamination of the rock. The streaks of granulated grains, where present, are commonly parallel to both biotite directions, but in some rocks they are randomly oriented. The color of the Z direction is olive gray (5Y) in most rocks, although near the margins of the body it is commonly dark yellowish brown (10YR). Epidote occurs both as discrete grains and as oriented inclusions in plagioclase. Allanite grains, although not abundant, may be 5 mm or more long, and are commonly mantled by euhedral epidote. Muscovite in many rocks occurs only as oriented inclusions in plagioclase, although in some it forms discrete flakes aligned parallel to the biotite flakes. The rock is commonly fresh and shows only minor chloritization of biotite and sericitization of plagioclase. Cataclastic deformation of the rock is only locally strong, although minor streaks of granulated minerals were observed in about half the samples studied.

Eastford Gneiss

The Eastford Gneiss forms another large sill of light-gray biotite gneiss, primarily of quartz monzonite composition. It occurs in the northern part of the Hampton quadrangle (pl. 3) primarily in the Hebron Formation, but partly adjacent to Scotland Schist. The Eastford Granite-Geniss was named by Gregory (in Rice and Gregory, 1906) for exposures in the town of Eastford. He compared the appearance of the gneiss with the Monson Gneiss, and Foye (1949) included the Eastford with his Monson. The name was changed (pl. 3) to Eastford Gneiss. The name Eastford is used here only for the northern part of the body of Eastford as it was shown on earlier maps (Foye, 1949; Rodgers et al, 1956), which occurs in the town of

Eastford. The recent work in eastern Connecticut indicates that the correlation and comparison of Eastford Gneiss and Monson Gneiss is not valid as the two rock units are compositionally and structurally different. In its general composition and mode of occurrence the Eastford is similar to the Canterbury gneiss, and the two sills are no doubt genetically related, although it is not clear whether or not they ever connected to form one body; probably they did not. The Eastford Gneiss as mapped so far occurs only in the recumbent limb of the Hampton syncline, and the Canterbury is in the normal limb.

The Eastford Gneiss extends north of the Hampton quadrangle for about 6 miles and southwest of the quadrangle for probably about 3 miles; it thus has an approximate length of about 15 miles. In the thickest part, across the northern edge of the Hampton quadrangle, the unit has a maximum apparent thickness of about 3,000 feet. The arm of gneiss in the western part of the quadrangle, west of Halls Pond has a thickness of about 1,500 feet, and possibly this is about the original thickness of the sill. There are two foliations in the gneiss, one of which is variable in dip from horizontal to vertical, and suggests the sill may have been folded. The sill trends northwest and apparently dips northwest at a moderate angle, although the contact with the enclosing Hebron Formation has not been observed. The contact is apparently faulted locally; the eastern contact is probably along a fault, and local cataclasis of the Hebron close to the western contact suggests some faulting along that contact.

The rock of the Eastford Gneiss is primarily a medium-grained, light-gray biotite quartz monzonite gneiss commonly with a minor amount of megascopic muscovite. The foliation is defined mainly by orientation and alignment of biotite flakes; less commonly it is expressed by quartz and feldspar rich streaks. In most of the rock there are two directions of biotite orientation. One direction is generally parallel to the regional foliation, and has a north-northeast strike and a moderate northwest dip. The other foliation plane is variable in attitude and is probably the original, or earlier foliation. Much of the Eastford is fairly poor in biotite and in these rocks either or both foliations are difficult to see. Clusters of biotite flakes are streaked out along the intersection of the two foliations to give a strong lineation, which is commonly more prominent than either foliation. The lineation commonly has a shallow plunge north-northeast. A lens of small-grained, very-light-gray alaskite can be traced for less than a mile in the northern part of the Hampton quadrangle, and has a maximum thickness of about 200 feet. West of Halls Pond, near the western edge of the Hampton quadrangle is a lens of biotite rich granular gneiss; its dimensions were not observed but it is apparently small. Aplite dikes in the Eastford occur throughout the unit, they are as much as a foot thick and may cut the foliation at a high angle. The aplites are, thus in contrast to thin, corcordant sills which are observed only near the base of the Canterbury Gneiss. Small inclusions of an unknown source occur locally in the Eastford. They are commonly a few inches long and about an inch thick. Most are fine-grained biotite-quartz-plagioclase gneiss, although a few are amphibolite. The edges of the inclusions are commonly parallel to the original foliation planes.

An excellent exposure of Eastford Gneiss occurs along a gas line in the central part of the Hampton quadrangle (pl. 3) where the till has been scraped off the bedrock for almost a mile across the strike of the regional foliation. A prominent feature of the unit, which is readily observed in the gas line, is small shear zones, commonly no more than 10 feet long, that fade out into unsheared rocks at either end. The shears bend or offset both foliation planes, aplites and some pegmatites; they are in turn cut by other pegmatites and some contain pegmatitic rock along the shear plane. Less common, and less obvious are thin streaks of finely granulated or mylonitized rock. These are about an inch thick and tens of feet long. In one place mylonite can be seen to feather out into apparently ungranulated rock. The mylonite streaks have a strong northerly trend; a dip was observed on only one and it was steep to the southeast. The rest of the Eastford Gneiss is not commonly cataclastic, and only locally do the rocks show limited streaks of granulation.

Modal analyses of samples of Eastford Gneiss are given in table 13. Most of the Eastford is a medium-grained, light-gray biotite-microcline-quartz-oligoclase gneiss. Oligoclase makes up 30 to 45 percent of most rock, and averages about 35 percent; quartz is 25 to 35 percent, and averages about 30 percent; microcline is 15 to 35 percent and averages about 30 percent; and biotite is 3 to 10 percent, and is commonly about 5 percent. Much of the Eastford contains 1 or 2 percent muscovite. Accessory epidote and allanite, which are common in the Canterbury Gneiss, are rare in the Eastford, while accessory garnet, although not abundant, is more common in the Eastford than in the Canterbury. Other accessory minerals include apatite, zircon, opaque minerals, and less commonly sphene. The lens of alaskite gneiss (table 13, H3-6) consists of a white, small-grained muscovite-microcline-quartz-oligoclase gneiss with minor garnet. The alaskite is quite uniform in composition, and contains about 40 percent albite, 30 percent quartz, 18 percent microcline, 12 percent muscovite and less than 1 percent garnet and apatite. The biotite rich granular gneiss (table 13, HO-58) contains about 30 percent biotite and minor microcline and muscovite. The lens may be an inclusion in the Eastford, or it may be an example of a "black knot" referred to by Chayes (1952) in the New England granites.

The rock of the Eastford Gneiss is commonly an even-grained, granular gneiss. The average grain size of the quartz and feldspars in an individual rock ranges from about 0.5 mm to 1.5 mm, but in most is about 1 mm. Feldspar may occur locally in coarse grains, but the euhedral laths which commonly occur in the Canterbury Gneiss are rare. The composition of the plagioclase is commonly An 20 to An 25. Both microcline and plagioclase may contain minor, fine, perthitic intergrowths of the other feldspar. Muscovite in the Eastford commonly occurs as discrete grains with the biotite. The color of the biotite does not show the same consistency as in the Canterbury Gneiss. In about half the samples examined biotite is olive gray (5Y), and in the other half it is grayish brown (5YR). The color differences show no apparent relationship to position in the body or proximity to the edge of the body. The minor epidote of the rock occurs only as inclusions in plagioclase, and does not form discrete grains as in the Canterbury Gneiss.

Age and correlation

Within the Plainfield-Danielson area the age of the Canterbury and Eastford Gneisses can be established as younger than the Hebron Formation and the same age as or older than the regional metamorphism. Evidence in the Fitchville quadrangle (Snyder, 1964a) suggests that the Canterbury is also younger than the Scotland Schist. Zartman et al (1965) report a whole rock rubidium-strontium age of 430 $\pm$ 20 m.y. for the Canterbury Gneiss. If this number dates the time of intrusion, or of crystallization of the rock, it would suggest a late Ordovician or early Silurian age. The whole rock isochron, however, is based on four samples of Canterbury, only two of which are from the sill which goes through the town of Canterbury. The other two samples are from other bodies of gneiss which are called Canterbury; one is on the west side of the Willimantic dome in the Columbia quadrangle (Snyder, 1967) and the other is the thin, detached sill in the southern part of the Fitchville quadrangle (Snyder, 1964a). The latter is close enough to the Honey Hill fault that much of the rock is at least partially cataclastic. Further work is needed, therefore, to determine whether the 430 m.y. age is a reliable age for the Canterbury. Efforts to obtain a radiometric age for the Eastford Gneiss have not yet been successful. Zartman (written communication, 1964) analysed a sample of the alaskite gneiss in the Eastford, and obtained a 380 m.y. number, using an assumed initial Sr^{87}/Sr^{86} ratio of 0.705 (the same as the Canterbury Gneiss). In reporting the age, however, Zartman cautioned that rock of this type that might have its age lowered by diffusion of Sr into the surrounding rock during metamorphism. It is also possible that the alaskite is intrusive into, and younger than the surrounding Eastford Gneiss.

The Canterbury and Eastford Gneisses are commonly correlated with the rocks of the New Hampshire Plutonic Series of New Hampshire (Billings, 1956). The composition, mode of occurrence and texture of the rocks are in general similar to the New Hampshire Plutonic Series. The latter rocks intrude rocks as young as the Littleton Formation, and their foliation and lineation is parallel to that of the surrounding rocks (Billings, 1956, p. 127), and thus have been dated as middle or upper Devonian. If Scotland Schist is correlative with the Littleton Formation, the Canterbury and

Eastford Gneisses must also be middle to upper Devonian.

The Canterbury Gneiss has also been commonly correlated with the Ayer Granite of Massachusetts (Foye, 1949; Rodgers et al, 1959). Preliminary work north of the Plainfield-Danielson area, in the Putnam quadrangle, indicates that Canterbury Gneiss is again exposed, north of the village of Putnam and is continuous with a belt of Ayer Granite in Massachusetts. The belt extends from the state line northward to Worcester, and its composition, mode of occurrence as a sill in Hebron type rocks and texture indicate that this belt of Ayer is equivalent to the Canterbury. It is likely, however, that rocks of different ages have been grouped under the name of Ayer (see Zartman et al, 1965), and how much of the Ayer as shown on the geologic map of Emerson (1917) is correlative with the Canterbury Gneiss cannot be determined until more mapping is done in Massachusetts.

Chemistry of the Canterbury and Eastford Gneisses

Chemical analyses of four samples of Canterbury Gneiss are given in table 21. The average analysis given in column 5 is the average of eight analyses, including the four given here and the four given by Snyder (1964a) from the Fitchville and Norwich quadrangles. The average of the eight is very close to the averages of the two sets of four analyses, and is probably very close to the average composition of the sill. The analyses of the Canterbury Gneiss are in general comparable to analyses of the New Hampshire Magma Series given by Billings and Wilson (1964). The average analysis of the Canterbury Gneiss is quite similar to an analysis of the Concord Granite (Billings and Wilson, 1964, table 11, number 13).

No chemical analyses are available of the Eastford Gneiss for direct chemical comparison of the two units. In general the Eastford Gneiss contains more microcline and slightly more muscovite, and less biotite and calcium bearing accessory minerals such as epidote, allanite and sphene. The differences in microcline and biotite between the two units are illustrated in figure 6, in which modal ratios of quartz, feldspars and biotite in 22 samples of Canterbury Gneiss and 13 samples of Eastford Gneiss are plotted on triangular diagrams. Although there is some overlap, the diagrams illustrate the general greater amount of microcline and lesser amount of biotite in the Eastford Gneiss. The mineralogical differences between them probably reflect a greater amount of K_2O and less amount of CaO, FeO and MgO in the Eastford Gneiss than in the Canterbury Gneiss. The K_2O:Na_2O ratio of the Canterbury averages close to 1; in the Eastford Gneiss it is probably slightly higher.

Of the eight analyses of Canterbury Gneiss now available six are from the eastern side of the sill, one is from the western side, and one is from the disconnected sill in the southwestern part of the Fitchville quadrangle. The normative (C.I.P.W.) quartz and feldspar ratios for the analysed Canterbury Gneiss are plotted in figure 7; quartz:orthoclase: plagioclase are shown in figure 7a and quartz:orthoclase:albite are shown in figure 7b. The ratios for the gneiss from the southwestern part of the Fitchville quadrangle are shown by a separate symbol, although in both diagrams it falls very close to the ratios for the average Canterbury. In figure 7a the analyses are marked with t, m or b, to indicate samples collected near the top, middle and bottom of the sill respectively. The spread of the points between the two feldspars suggests that ratio of orthoclase to plagioclase is not related to position in the sill. The ratios of total alkalies (K_2O+Na_2O):FeO:MgO for the analysed Canterbury Gneiss are shown in figure 8. The points fall along a line indicating a fairly constant FeO:MgO ratio in the rocks.

The modal analyses (table 13) of the analysed samples of Canterbury Gneiss agree quite closely with the mesonorms (table 21) calculated from the chemical analyses, suggesting that there is very little solid solution in the feldspars. This is also suggested by the scarcity of perthitic intergrowths of the two feldspars. The Canterbury Gneiss would, thus, fit into Tuttle and Bowen's (1958 p. 129) category of IIC granites, subsolvus granites in which the potassium feldspar contains less than 15 percent albite. Tuttle and Bowen suggest that all IIC granites have been recrystallized subsequent to consolidation. The strong regional foliation superimposed on an apparently earlier foliation in most of the Eastford Gneiss and much of the Canterbury Gneiss would indicate that this is a reasonable suggestion for Canterbury and Eastford.

Table 13.--Modal analyses of the Canterbury and Eastford Gneisses.

	Canterbury Gneiss						Eastford Gneiss				
	S8-189 *	H8-109 *	H3-7	H3-1	S8-115 *	S7-97 *	H3-5	H3-57	HO-105	H3-6	HO-58
Quartz...........	26	33	41	31	28	28	28	33	30	34	21
Plagioclase......	42	47	33	43	40	46	33	33	31	41	44
Microcline.......	21	3	21	10	20	12	29	25	31	12	1
Biotite..........	6	15	4	10	9	10	7	9	5		30
Muscovite........	2 3/	0.8	0.8	4	0.3 3/	1	2	0.1	3	13	1
Epidote..........	2	0.2	0.5	0.6	1	2	x		x		x
Allanite.........	x	0.2	x	x	x	x		x			0.3
Zircon...........	x	x	x		x	x	x	x	x		0.2
Apatite..........	x	0.6	0.1	0.3	x	x	0.3	0.2	0.3	0.2	1
Sphene...........	0.5	x	x	0.2	0.5	0.4	x	x	x		
Opaques..........	x	0.3		0.1	x	x	x	x	x		0.7
Garnet...........			0.1							0.2	
Chlorite 1/.......	x(b)	x(b)	0.2(b)	x(b)	x(b)						x(b)
Sericite 2/.......	x(p)	x(p)	0.1(p)	x(p)				x(p)			x(p)
Plag. comp.......	An23	An23	An22	An25	An27	An28	An25	An25	An25	An5	An27

Percentages rounded off to the nearest whole number, except those less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.
*Samples for which chemical analyses are reported in table 21.
1/ Chlorite from (b) biotite.
2/ Sericite from (p) plagioclase.
3/ Muscovite almost all as alteration, and commonly as oriented inclusions in plagioclase.

Canterbury Gneiss:

S8-189 (S-32.3N; 4.7W): Medium-light-gray, medium-grained, biotite-quartz-feldspar gneiss. Foliation is defined by planar arrangement of biotite flakes parallel to biotite rich, quartz rich and feldspar rich laminae. In thin section the quartz in the quartz rich laminae is in granular grains with an average size of about 1 mm and that in the feldspar rich laminae is in fine grains with moderately sutured boundaries. Plagioclase is myrmekitic adjacent to microcline. About half the muscovite is in plates parallel to the biotite orientation and the rest occurs as oriented inclusions in the plagioclase. Biotite is olive gray (10Y 3/2). Average grain size is about 1 mm.

H8-109 (H-5.7N; 25.8W): Medium-gray, small-grained biotite-quartz-feldspar gneiss. Foliation is defined by planar orientation and arrangement of biotite flakes, and fine, discontinuous streaks of feldspar. A second foliation at a high angle to the main one is defined by streaks of biotite flakes. The thin section shows fine, discontinuous streaks of granulated grains parallel to both directions of biotite orientation, but most parallel the more prominent direction. The granulated areas account for less than 5 percent of the sample; in these quartz and feldspar are fine grained and quartz is moderately sutured. In the rest of the rock the grains are granular, with smooth boundaries and an average size of 0.5 mm. Biotite is grayish olive (10Y 4/2).

H3-7 (H-27.6N; 4.5W): Light-gray, small-grained biotite-quartz-feldspar gneiss. Foliation is defined by planar orientation and arrangement of biotite flakes. Fine biotite laminae separate quartz and feldspar laminae. A weak second foliation is formed by fine, discontinuous streaks of biotite at an angle to the prominent foliation. Streaks of biotite flakes give a strong lineation. In thin section fine, discontinuous streaks of granulation are parallel to both directions of biotite orientation. In these the very-fine-grained quartz is strongly sutured. In the rest of the rock quartz is in even grains with weak suturing. Plagioclase is myrmekitic adjacent to the microcline, and some plagioclase is slightly zoned. Most muscovite is apparently secondary. Biotite is olive gray (5Y 3/2). Average grain size is about 0.7 mm.

H3-1 (H-11.3N; 6.6W): Medium-light-gray, small-grained muscovite-biotite-quartz-feldspar gneiss. Foliation is similar to H3-7, although the second biotite foliation plane is stronger. Coarse feldspar grains are as much as 1/2 inch long. In thin section areas and streaks of granulation are in part parallel to the direction of mica orientation and in part are randomly oriented. Quartz is strongly sutured in the granulated areas and weakly sutured in the rest of the rock. About 5 percent of the sample is granulated. Plagioclase is slightly myrmekitic adjacent to microcline, and some plagioclase is complexly zoned from about An 20 to An 30. Grain size is variable, but averages about 0.5 mm. Biotite is olive gray (5Y 3/2).

S8-115 (S-22.7N; 17.0W): Medium-light-gray, medium-grained biotite-quartz-feldspar gneiss. Foliation is similar to H3-7, including the second biotite foliation. Coarse feldspar grains are as much as 1/2 inch long. The thin section shows only a few, small local areas of granulation; most of the rock is even grained, with an average size of about 1.5 mm, except for the coarse feldspar grains. Quartz is weakly sutured. Myrmekite is prominent around the coarse microcline grains; about 15 percent of the plagioclase is myrmekitic. The minor muscovite is secondary after plagioclase and occurs mostly as oriented inclusions in plagioclase. Some epidote surrounds medium-sized allanite grains. Biotite is grayish olive green (5GY 3/2).

S9-97 SS-3.4N; 27.0W): Medium-gray, medium-grained biotite-quartz-feldspar gneiss. Foliation is well defined by planar orientation of biotite flakes and of streaks of quartz and feldspar. A second foliation is defined by streaks of biotite flakes and most of the muscovite of the rock. The thin section shows streaks and areas of granulation which account for about 10 percent of the rock; in these quartz is strongly sutured; quartz in the rest of the rock is not sutured. Thin granulated shells commonly surround the microcline. The grain size is variable; in the ungranulated parts of the rock it averages about 0.8 mm. Biotite is grayish olive (10Y 4/2).

Eastford Gneiss:

H3-5 (H-42.2N; 13.3W): Light-gray, small-grained biotite-quartz-feldspar gneiss. Two foliation planes are defined by planar orientation and arrangement of the biotite flakes. Biotite flakes are aligned at the intersection of the foliations to give a strong lineation. The rock is even grained and granular with an average size of about 0.6 mm, and without streaks or zones of granulation. Quartz boundaries are not sutured. A minor amount of myrmekite is developed in the plagioclase adjacent to the microcline. Biotite is olive gray (5Y 3/2). Muscovite flakes are parallel to both directions of biotite orientation.

H3-57 (H-32.4N; 17.9W): Light-gray, medium-grained biotite-quartz-feldspar gneiss. The two biotite foliationsand lineation are similar to H3-5. In thin section the rock is also similar to H3-5. Biotite is olive gray (5Y 3/2). Average grain size is about 1.2 mm.

HO-105 (H-35.4N; 15.4W): Light-gray, medium-grained muscovite-biotite-quartz-feldspar gneiss. The two biotite foliations and lineation are similar to H3-5. In thin section, the rock is also similar to H3-5. Biotite is olive gray (5Y 3/2). Average grain size is about 1 mm.

H3-6 (H-42.6N; 13.6 W): Yellowish-gray, small-grained muscovite-quartz-feldspar gneiss. Foliation is defined by planar orientation of the muscovite flakes. A possible second foliation at an angle to this is marked by streaks of quartz and muscovite rich laminae and feldspar rich laminae, and some muscovite appears to be oriented parallel to the streaks. Both foliations are difficult to see because of the uniform color of the rock. In thin section there are minor thin zones of granulation, in particular around some of the microcline. Quartz is not sutured, but the quartz-plagioclase contacts are commonly irregular and coarsely sutured looking. Average grain size is about 0.5 mm.

HO-58 (H-32.3N; 32.3W): Medium-dark-gray, fine-grained quartz-biotite-feldspar gneiss. The rock is granular with a weak foliation plane defined by subparallel biotite flakes. The sample contains a few scattered coarse plagioclase grains as much as 1/4 inch long. In thin section the grains are even and granular with an average size of about 0.3 mm. Quartz is not sutured. Biotite is moderate brown (5 YR 4/4).

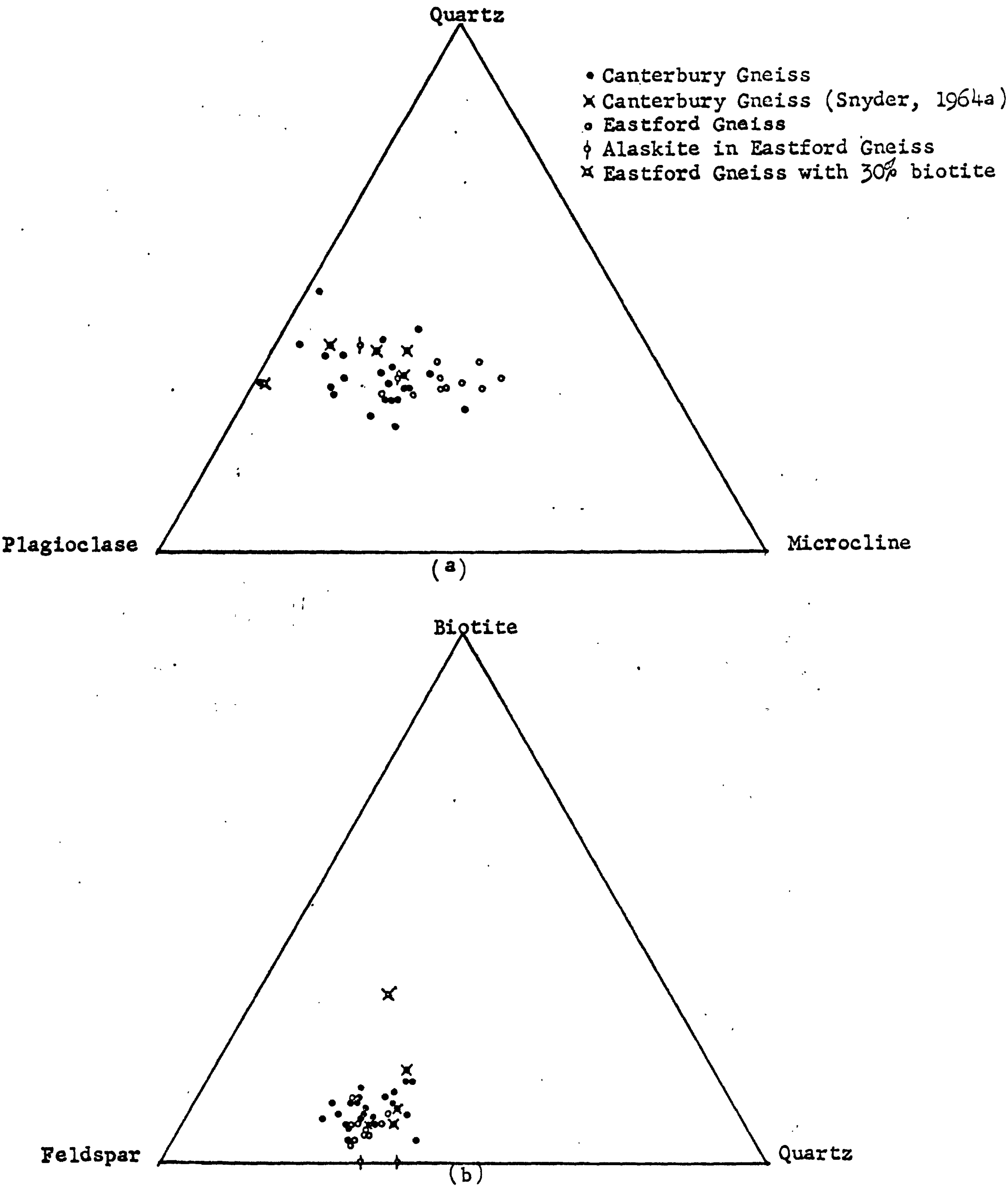


Figure 6.--Triangular diagrams of Eastford and Canterbury gneisses.
(a) Plot of modal quartz-plagioclase-microcline
(b) Plot of modal biotite-total feldspar-quartz

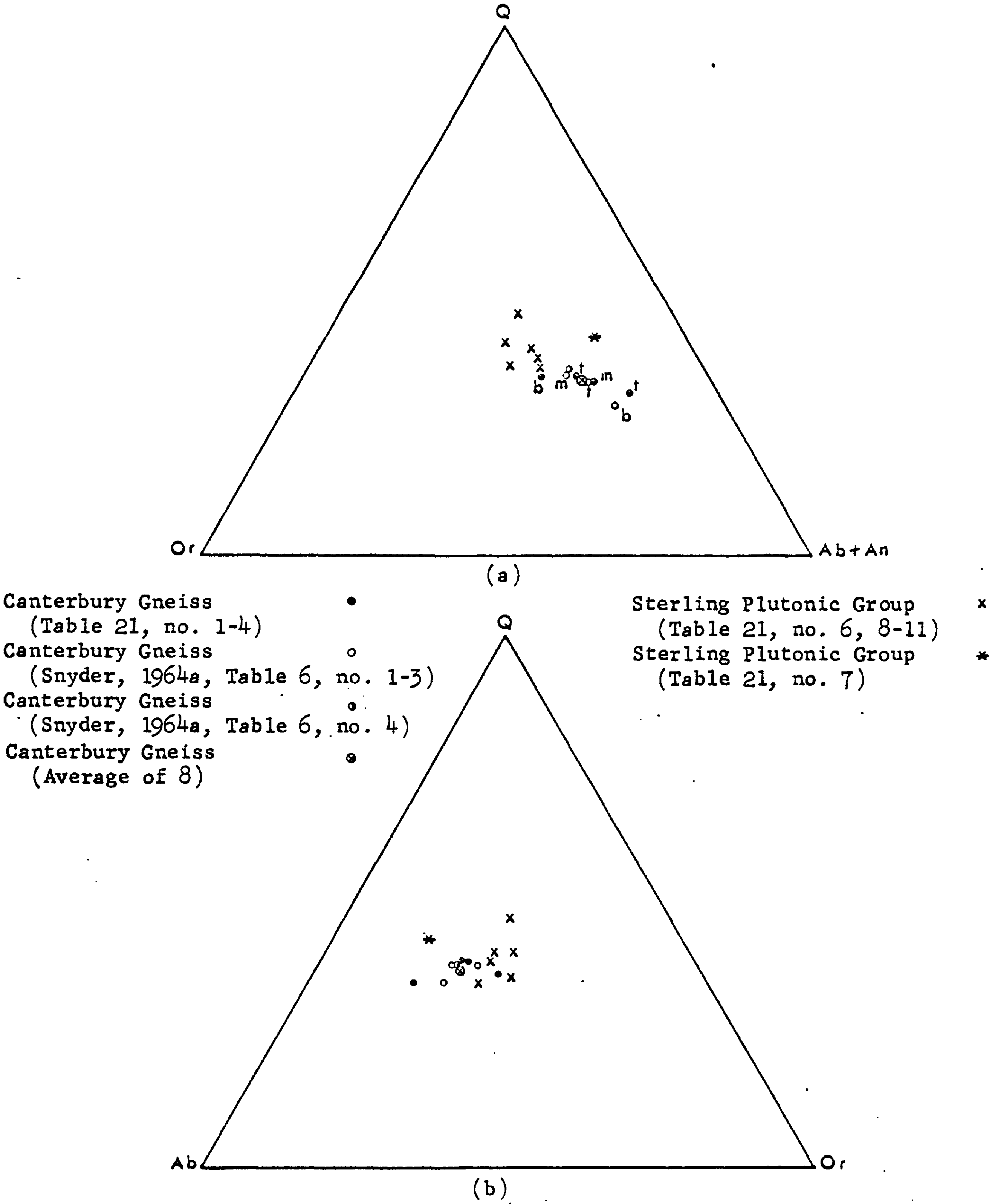


Figure 7.--Triangular diagram showing the normative (C.I.P.W.) ratios of quartz and feldspar in the analysed samples of Canterbury Gneiss and Sterling Plutonic Group.

(a) Quartz:orthoclase:anorthite+albite (b, sample from the bottom of the sill; m, sample from the middle; t, sample from the top of the sill).

(b) Quartz:orthoclase:albite.

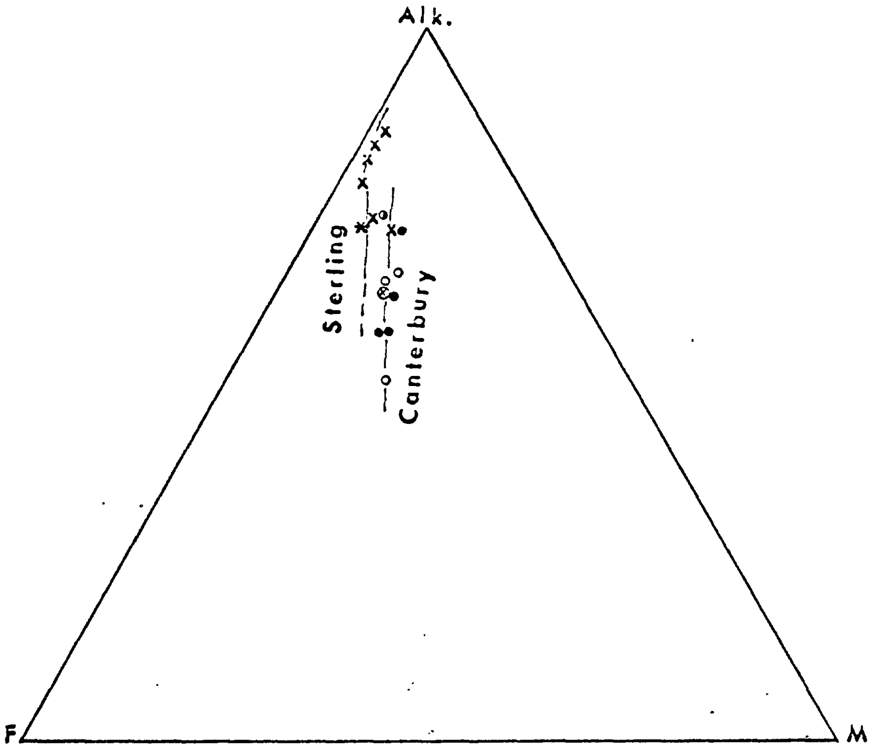


Figure 8.--Triangular diagram showing the ratios of total alkali (Na_2O+K_2O):FeO:MgO in analysed samples of the Canterbury Gneiss and Sterling Plutonic Group.

- • Canterbury Gneiss (Table 21, no. 1-4)
- o Canterbury Gneiss (Snyder, 1964a, Table 6, no. 1-3)
- ◉ Canterbury Gneiss (Snyder, 1964a, Table 6, no. 4)
- ⊗ Canterbury Gneiss (Average of 8)
- x Sterling Plutonic Group (Table 21, no. 6, 8-11)
- * Sterling Plutonic Group (Table 21, no. 7)

Sterling Plutonic Group

The name Sterling Granite-Gneiss was used by Gregory (in Rice and Gregory, 1906) for a variety of gneissic rocks along the southern and eastern edge of eastern Connecticut, including those gneisses in the lower plate of the Lake Char fault in the Plainfield-Danielson area. Most of the western half of Rhode Island was shown by Emerson (1917) as Sterling Granite Gneiss. Quinn (1951) and Moore (1958) subdivided the Sterling of Rhode Island into several units, the largest of which are the Scituate Granite Gneiss (Quinn, 1951) and the Hope Valley Alaskite Gneiss (Moore, 1958). Goldsmith (1966) separated the Sterling gneisses of the area south of the Honey Hill fault into several lithologic types and changed the name to Sterling Plutonic Group. Some of his lithologic units are probably equivalent to the named units in Rhode Island, but he did not apply specific names to them as the units in his area have not been mapped continuously into correlative units in Rhode Island. Feininger (1965b) used the name Hope Valley Alaskite Gneiss for the alaskitic gneisses in the Voluntown quadrangle, and this name was used for the continuation of these rocks in the Plainfield quadrangle (pl. 4). Moore (personal communication, 1966) agreed that the gneisses in the Plainfield quadrangle are equivalent to the Hope Valley, but would designate most of those in the Danielson quadrangle as Scituate Granite Gneiss, and this name has been used on plate 2. Probably the Sterling rocks are restricted to the lower plate of the Lake Char fault; they have not been identified with certainty associated with the Quinebaug Formation above the fault, although it is possible that the cataclastic two feldspar gneisses may be correlative with the Sterling.

The rocks of the Sterling Plutonic Group are poorly exposed in the Plainfield-Danielson area, and the majority of those that are exposed are close to the Lake Char fault and are thoroughly cataclastic. Differences in mineralogy and texture between the Hope Valley Alaskite Gneiss and the Scituate Granite Gneiss are, therefore, difficult to see in the rocks of the area. In the southeast corner of the Plainfield quadrangle some normal, noncataclastic alaskite gneiss is exposed. The rock is a pinkish-gray to grayish-orange, medium-grained, weakly foliated quartz-feldspar gneiss. Quartz rods are aligned to give a pronounced lineation, which is typical of the Hope Valley Alaskite Gneiss (Moore, 1958). The alaskite is gradational into a light-gray to grayish-orange, small-grained biotite gneiss (hvb on plate 4) in which biotite flakes are aligned and oriented parallel to laminae of quartz and feldspar. The rocks exposed in the rest of the area are light-gray to pinkish-orange cataclastic gneisses. The segregation of quartz and feldspar into alternating laminae is more prominent in the mortar gneisses and mylonite gneisses than in the noncataclastic gneisses. Coarse orange-pink potassium feldspar grains are commonly lined up parallel to the laminae. The mylonites are very-fine-grained, very hard, dense rocks of differing characteristics. Many of them are light-greenish gray, thinly laminated rocks and others are dirty greenish-gray or pale-red diffusely laminated or structureless. The alaskite mylonite is commonly difficult to distinguish from quartzite mylonite.

Modal analyses of some of the Sterling Plutonic Group are given in table 14. The gneisses contain 25 to 40 percent each quartz and plagioclase, 20 to 35 percent microcline, and 0 to 5 percent biotite and muscovite. The alaskite commonly contains muscovite and little or no biotite (table 14, P1-218). The biotite gneiss (table 14, P2-215) and Scituate Granite Gneiss (table 14, D2-277, D2-286) of this area rarely contain more than 5 percent biotite. The mineral content of the rocks of the Plainfield-Danielson area, however, are not necessarily typical of most of the Sterling because of the strong cataclastic deformation of most rocks. In table 14, only sample P1-218 is a normal, noncataclastic rock. Accessory minerals include epidote (probably neomineralized from plagioclase) sphene, apatite, opaque minerals (mostly magnetite) and minor zircon.

The noncataclastic alaskite gneiss in the southeastern corner of the Plainfield quadrangle (table 14, P1-218) is an even-grained, granular rock with an average grain size of about 1 mm. Quartz grains are not sutured, and most of them show moderate undulose extinction. The potassium feldspar is well twinned microcline. The composition of the plagioclase is about An 20; plagioclase is not zoned, and contains only minor, thin perthitic lamellae of potassium feldspar (see plate 12, fig. 1). The rest of the rocks are mortar gneisses, mylonite gneisses, mylonites and blastomylonites. The mortar gneisses contain streaks of granulated quartz and feldspar between laminae of ungranulated small- to medium-grained quartz and feldspar. As the degree of granulation increases the granulated streaks merge to become a matrix for the ungranulated minerals, mainly feldspars (pl. 12, fig. 2). Quartz in the granulated streaks and matrix is strongly sutured. The coarse feldspar grains adjacent to the granulated areas have ragged irregular boundaries (pl. 12, fig. 4). In some rocks feldspar grains are broken, and the fractures filled with very-fine-grained quartz and feldspar. The mylonites are fairly uniform very-fine-grained rocks containing a few fine-grained feldspars (pl. 12, fig. 3). In many rocks biotite is partially altered to chlorite. Plagioclase is also partially altered to sercite, and locally is strongly sericitized. Most epidote, muscovite and calcite, all of which occur in minor amounts in the mylonite gneisses and mylonites, are apparently neomineralized from plagioclase. Both plagioclase and microcline commonly show irregular, wavy perthitic lamellae of the other feldspar, and plagioclase may be zoned. Quartz and feldspar in the very-fine-grained matrix are commonly difficult to distinguish without staining the thin section for both feldspars, and this was done for all of the moded samples except P1-218.

Age and correlation

In the Plainfield-Danielson area the age of the Sterling Plutonic Group can be established only as younger than the Plainfield Formation and older than the cataclastic deformation. South of this area, the Sterling gneisses form concordant to locally cross-cutting sills in rocks as young as the Monson Gneiss (Goldsmith, 1966), but they have not been recognized in rocks younger than Monson. In Rhode Island gneisses equivalent to the Sterling unconformably underlie the Pennsylvanian rocks of the Narragansett basin (Goldsmith, 1966). Lundgren (1966a) suggested that some of the concordant sills of the Sterling might be metamorphosed felsic volcanic rocks of the same age as the Monson Gneiss, and other parts of the Sterling were intrusive rocks associated with the middle Ordovician volcanic activity which was the source of the Monson. The Sterling is, however, comparable in general composition, mode of occurrence and stratigraphic position of the rocks it occurs with, to some of the Oliverian Plutonic Series of New Hampshire, which has been dated as middle or upper Devonian(?) (Billings, 1956). The age of the Sterling Plutonic Group is, therefore, middle Ordovician or younger, and pre-Pennsylvanian.

Chemistry

Chemical analyses of some rocks of the Sterling Plutonic Group are given in table 21. Analyses 6 to 9 are of cataclastic Sterling from the Plainfield-Danielson area, and 10 and 11 are of normal, noncataclastic Sterling collected by R. Goldsmith in the Uncasville quadrangle (Goldsmith, 1967a). The analyses of the cataclastic and noncataclastic rocks are closely comparable, suggesting there was little if any change in the chemical composition of the rocks during cataclasis. Analysis 7 (P2-179) differs to some degree from the others in that the $K_2O:Na_2O$ ratio is about 0.5, while in the other analyses the ratio is more than 1. Sample P2-179 shows a greater degree of neomineralization during cataclasis than the other samples, and possibly this rock lost some K_2O during cataclasis. The anomalous potassium content of P2-179 is reflected in the quartz-feldspar ratios plotted in figure 7. In figure 8 the total alkali:FeO:MgO ratios for the Sterling fall on the rather straight line, indicating a constant FeO:MgO, and the plot of P2-179 is consistent with the other plots. Thus the loss of K_2O in this sample is the only chemical change suggested by the analyses.

Comparison of the chemical analyses of the Canterbury Gneiss and the Sterling Plutonic Group shows differences which suggest the two groups of gneisses are not related. The $K_2O:Na_2O$ ratio of the Canterbury is close to 1, and of the Sterling is consistently greater than 1. The difference is reflected in the quartz and feldspar ratios plotted in figure 7; the Sterling plots are all (except P2-179) richer in <u>Or</u> than the Canterbury plots. The FeO:MgO ratio of the Canterbury is close to 2 and in the Sterling gneisses is greater than 2 and may be as much as 5. This difference is shown in the triangular diagram of figure 7 which plots the ratio of total alkalies:FeO:MgO. The plot of one Sterling analysis from the Uncasville quadrangle falls off the line defined by the other Sterling plots; this sample is fairly high in normative biotite as compared to the other Sterling rocks.

Table 14.--Modal analyses of the Sterling Plutonic Group.

	P1-215 *	P2-179 *	D2-277 *	D2-286 *	P1-218
Quartz	26	31	41	36	37
Plagioclase	34	43	28	32	36
Microcline	35	15	28	28	25
Biotite	4	0.6	1	0.1	x
Muscovite		3 5/		0.8 5/	2
Sphene		2	0.2		
Apatite		x			x
Opaque minerals	0.4	2	0.1	0.6	0.6
Zircon	x				
Epidote 1/		1	0.2		
Sericite 2/	x	0.4			
Chlorite 3/	1	1	0.4	2	
Calcite 4/			0.2	x	
Limonite		0.7			
Plagioclase composition	An15	An12	An7	An5	An20

* Samples of which chemical analyses are reported in table 21.
1/ Epidote is secondary after plagioclase.
2/ Chlorite is mostly after biotite.
3/ Sericite is after plagioclase.
4/ Calcite is after plagioclase.
5/ Muscovite secondary after plagioclase and biotite.

Sterling Plutonic Groups:

P1-215 (P-0.2N; 7.3W): (Hope Valley Alaskite Gneiss, hvb on pl. 4) Medium light-gray, small-grained biotite-quartz-feldspar mortar gneiss. Moderate-orange-pink megacrysts of microcline are as much as an inch long; most are aligned parallel to the biotite schistosity, but some are at a high angle to it. In thin section medium-grained feldspar is in a fine- to very-fine-grained matrix of granulated quartz and feldspar. The matrix makes up about one-third of the rock, and is streaked out parallel to the biotite alignment between the coarser feldspars. In the matrix most quartz and feldspar are too fine grained to distinguish without staining. Quartz is strongly sutured. Biotite is moderate olive brown (5Y 4/4) and is partially chloritized. Grain size is variable.

P2-179 (P-21.2N; 8.6W): (Hope Valley Alaskite Gneiss(?) between two slices of the lake Char fault.) Brownish-black on the weathered surface, greenish-gray on the fresh surface, very-fine-grained mylonite gneiss. Cataclastic foliation is a diffuse lamination, with alternating fine greenish chloritic streaks, gray quartz and feldspar streaks and discontinuous wider (as much as 0.2 inch) orange-pink streaks of potassium feldspar. Sample is very hard, dense and difficult to break with a hammer. In thin section the fabric is similar to P1-215, except that the matrix is over one-half of the rock and is all very fine grained and the coarser feldspar grains are mostly small grained. The matrix and aggregates of small-grained feldspar are streaked out to form to cataclastic foliation. Quartz is strongly sutured. Biotite is moderate olive brown (5Y 4/4) to green, and is partially chloritized. Grain size is variable.

D2-277 (D-9.6N; 1.5W): (Scituate Granite Gneiss.) Variegated light-gray, coarse-grained biotite-quartz-feldspar gneiss. Two foliation planes are defined by alignment of biotite flakes and streaks of quartz and feldspar; both features reflect both planes, but one plane is more prominent than the other. Linear aggregates of biotite at the intersection of the two planes form a strong lineation. Streaks of orange-pink potassium feldspar aggregates are over an inch long, and individual grains, with a good cleavage surface and Carlsbad twins may be 1/2 inch long. In thin section the coarse feldspar and streaks of small-grained quartz are in a very-fine-grained matrix of quartz and feldspar. The matrix makes up about one-fourth of the rock. Some feldspar grains are broken and the fractures are filled with very-fine-grained quartz and feldspar. Most of the matrix is streaked out parallel to the stronger of the two foliations. Quartz in the matrix is strongly sutured; the small-grained quartz is weakly sutured. Biotite is in aggregates, commonly with medium-grained sphene. Biotite is grayish olive (10Y 4/2). Grain size is variable.

D2-286 (D-29.0N; 0.1W): (Scituate Granite Gneiss.) Grayish-orange-pink, biotite-quartz-feldspar mortar gneiss. Foliation is defined by alignment of thin biotite flakes and discontinuous orange-pink potassium feldspar laminae. In thin section rock is similar to D2-277, except that the very-fine-grained matrix makes up over one-half of the rock. Some feldspar grains are broken and the fractures filled with very-fine-grained quartz and feldspar or with chlorite. The potassium feldspar commonly contains perthitic lamellae of twinned plagioclase. Plagioclase is complexly twinned and is commonly sharply zoned. Most biotite is chloritized. Grain size is variable.

P1-218 (P-3.4N; 0.3W): (Hope Valley Alaskite Gneiss.) Pinkish-gray, medium-grained muscovite-quartz-feldspar gneiss. Sample is weakly foliated, because of the scarcity of micas. Quartz rods form a strong lineation but are not laminated to form a foliation. In thin section the rock is granular with even grained smooth bounded quartz and feldspar. Quartz is not sutured and shows weak undulose extinction. The minor biotite is light olive (10Y 5/4). Average grain size is about 1 mm.

Pegmatites

Dikes and sills of quartz-feldspar rock cut all rock units in the area and are classified here under the general term of pegmatite. The pegmatites have a wide range in composition, grain size, size of body and degree of discordance; the most common is a foliated, medium-grained, light-gray muscovite-biotite quartz monzonite gneiss exposed in an outcrop 5 to 10 feet high and tens of feet long, and either concordant with the host rock or cutting it at a low angle. A special study of the pegmatites has not been made, and only a brief description is given here.

The pegmatites range in thickness from a few millimeters to tens of feet, and in length from a few feet to as much as a thousand feet. Many are too small to be mapped separately, and in general only those greater than 5 feet thick are shown on the geologic quadrangle maps. Although pegmatites are found in all the units throughout the area, they are locally concentrated. They are most abundant and largest in the Yantic and Fly Pond Members of the Tatnic Hill Formation, and it is rare to find outcrops of either unit without some pegmatite. One of the largest concentrations of pegmatite is in southern Scotland (plate 4) near Baltic Reservoir. The pegmatite here was mapped as Canterbury Gneiss by Gregory (in Rice and Gregory, 1906) and Foye (1949). Another large concentration is in the town of Canterbury near Cory Brook, near the eastern edge of the Scotland quadrangle. Pegmatites are also locally abundant near the contact of the Hebron Formation and Scotland Schist, as in the southern part of the Hampton quadrangle.

Modal analyses of several samples of pegmatite are given in table 15. The range in composition is from hornblende diorite to granite. The majority of the rock sampled are quartz monzonite, with approximately equal amounts of quartz, microcline and oligoclase, and minor biotite and muscovite; a few pegmatites are hornblende bearing. Accessory minerals in the pegmatites include garnet, epidote, apatite, zircon, tourmaline, sphene and opaque minerals. A few small grains of corundum and minor calcite are present in the hornblende pegmatites of the Hebron Formation. Radioactive and rare-earth mineral were reported by the landowner from a pegmatite in the southern part of the Hampton quadrangle. Variations in composition of the pegmatites can at present be correlated in only a general manner with the composition of the host rock. As a rule pegmatites cutting muscovite schists are muscovite bearing, and those cutting the calc-silicate gneisses carry biotite and no muscovite. The most striking correlation of pegmatite mineralogy to that of the host rock is seen in the pegmatites cutting the garnet-biotite gneiss of the lower member of the Tatnic Hill Formation. Garnet is a common accessory mineral in many pegmatites, but in most it is in small (about 1 mm), sparse grains. In the garnet-biotite gneiss, however, the pegmatites contain abundant garnet in grains up to 1 cm in diameter. Hornblende bearing pegmatites were found only near amphibolite in the lower member of the Quinebaug Formation, and as discordant, unfoliated pegmatites cutting the Hebron Formation.

Grain size of the pegmatites ranges from fine grained to coarse. The majority of the pegmatites have an average grain size of 1 to 2 mm; locally they may contain feldspars as much as 3 inches long. Most of the pegmatites are foliated, and the foliation is commonly parallel to that in the surrounding rock. Thus in the discordant pegmatites the contact between the pegmatite and the host rock is at an angle to the foliation of both rocks. The foliated pegmatites are most commonly concordant or slightly discordant. The unfoliated pegmatites are small (rarely more than 2 or 3 feet thick) and sharply discordant; they are most common as small dikes in the Canterbury and Eastford Gneisses. The degree of discordancy and size can be related in a general way to the intensity of metamorphism of the host rock. Pegmatites in rocks metamorphosed to sillimanite grade are most commonly concordant and small, while those near the sillimanite-staurolite isograd and within the staurolite zone tend to be more discordant and larger. In the Yantic Member of the Tatnic Hill the pegmatite locally has penetrated the schist and converted it to migmatite.

The origin of the pegmatites is open to speculation, and quite possibly not all originated from the same source. As they cut all rock units of the area, they are clearly younger than the rocks in which they now occur, though possibly some of the concordant bodies in the metavolcanic rocks of the Quinebaug and lowermost Tatnic Hill are metamorphosed felsic volcanic rocks rather than pegmatite. All pegmatites observed which are associated with cataclastic rocks are also cataclastic, and probably all pegmatites are older than the cataclasis. There are three main possibilities of genesis of the pegmatites: (1) They may represent the residual liquid from the Canterbury and Eastford gneisses. The largest bodies and concentrations of pegmatites occur near Canterbury Gneiss, and to a lesser degree near Eastford Gneiss. (2) They may have been sweated out of the enclosing rocks during metamorphism. This suggestion was challenged by Brookins and Hurley (1965) as a possible explanation of the Middletown pegmatites, west of this area, on the basis of dissimilar Sr (87/86) ratios for the pegmatites and the enclosing Brimfield Schist. The Middletown pegmatites are late, discordant, unfoliated pegmatites, and may have a different source than the foliated pegmatites. (3) The pegmatites may represent remobilized material from lower in the stratigraphic pile which moved up to the present level during or prior to regional metamorphism.

Table 15.--Modal analyses of pegmatite

	HO-116	S7-36	HO-28	S8-95	S8-103	HO-94
Quartz............	41	38	37	32	31	30
Plagioclase.......	46	26	52	21	15	46
Microcline........		26	8	33	49	
Biotite...........	2		2	7	3	5
Muscovite.........	11	10	0.5	6	2	
Epidote...........					x	1(p)1/
Allanite..........		x				
Zircon............	x	x	x	x	x	
Apatite...........	x	x	0.2	0.1	x	2
Sphene............				0.2	x	0.4
Opaques...........	x	0.3		0.1		x
Garnet............			x			
Tourmaline........			x			
Hornblende........						11
Corundum..........						x
Calcite...........						1
Chlorite2/........	x(b)		0.3(b,g)		0.3(b)	x(b,h)
Sericite3/........	x(p)	x(p)	x(p)		x(p)	3(p)
Plag. Comp........	An22	An20	An28	An23	An20	An40-60

All percentages rounded off to the nearest whole number, except those less than 1 percent; x indicates minerals present in amounts less than 0.1 percent.

1/ Epidote after (p) plagioclase.

2/ Chlorite after (b) biotite, (h) hornblende, (g) garnet.

3/ Sericite after (p) plagioclase.

Pegmatite:

S7-36 (S-5.1N; 7.7W): Very-pale-orange, small-grained, muscovite-quartz-feldspar gneiss. Sample has two foliation planes at an angle of about 25°, both defined by orientation of muscovite plates. Rock is slightly cataclastic and streaks of very-fine-grained, granulated quartz and feldspar parallel both foliation directions. Quartz grains are sutured in and near the granulated streaks, and elsewhere have smooth, angular boundaries. Grain size is variable from very fine grained to medium. Cuts sillimanite gneiss in the lower member of the Tatnic Hill Formation.

HO-116 (H-32.8N; 25.2W): Light-gray, stained-grayish-orange, medium-grained biotite-muscovite-quartz-feldspar gneiss. Rock is weakly foliated; foliation is defined by orientation of small, sparse biotite flakes. Average grain size is 1.5 mm. Biotite is moderate reddish brown (10R 4/6). Cuts Scotland Schist.

HO-28 (H-26.1N; 25.9W): Very-light-gray, medium-grained, biotite-quartz-feldspar gneiss. Foliation is weak because of paucity of micas, and is marked mainly by diffuse feldspathic bands. Average grain size is 1 mm. Biotite is moderate brown (5YR 3/4). Cuts Hebron Formation.

S8-95 (S-16.5N; 4.0W): Pale-yellowish-brown, medium-grained, muscovite-biotite-quartz-feldspar gneiss. Foliation is defined by planar arrangement of micas and feldspar laths. Sample is crossed by 1/8 inch quartz-feldspar band which cross the foliation at a low angle. Average grain size is 1 mm. Biotite is dark yellow brown (10YR 4/2). Plagioclase is myrmekitic near microcline grains. Cuts Yantic Member of the Tatnic Hill Formation.

S8-103 (S-24.6N; 0.8W): Light-gray, medium-grained, biotite-quartz-feldspar gneiss. Microcline forms megacrysts which average 1/4 inch diameter. Foliation is defined by planes of concentration of biotite and of feldspars. Average grain size is 1 mm. Biotite is moderate brown (5YR 4/4). About 25 per cent of the plagioclase is myrmekitic. Cuts contact between Yantic and Fly Pond Members of the Tatnic Hill Formation.

HO-94 (H-25.2N; 20.1W): Black mottled grayish-orange, coarse-grained, hornblende-plagioclase-quartz pegmatite. Slight yellowish weathering stain, especially on feldspar. Rock is not foliated. Average grain size is about 3 mm. Biotite is moderate yellow brown (10YR 5/4). Hornblende is dusky yellow green (5GY 5/2). Corundum is in fine (0.2mm) grains, pleochroic from pale blue to moderate blue (5B 5/6). Cuts Hebron Formation.

Gabbro

A small, coarse-grained gabbro sill is exposed in the Plainfield quadrangle (P. 23.4W; 37.9N). The exposure is 5 feet high and about 50 feet long, and is in the rusty weathering gneiss near the base of the Tatnic Hill Formation. The gabbro shows no indication of a foliation or of regional metamorphism. It is a medium-dark-gray rock composed of about 50 percent labradorite, and 25 percent each hornblende and diopside, and accessory opaque minerals and apatite. The plagioclase is somewhat altered, and at least some of the hornblende is after diopside. This alteration could be a late stage deuteric alteration, but more likely it is caused by recrystallization during cataclasis. The rocks surrounding the gabbro sill are mortar gneisses and mylonite, and the gabbro is probably older than the cataclasis. Both Loughlin (1912) and Sclar (1958) described small bodies of gabbro in the Putnam Gneiss west of the main body of Preston Gabbro. This sill is probably another small offshoot from the Preston Gabbro.

Quartz veins

Small quartz veins can be observed in many exposures of the Quinebaug Formation and the lower member of the Tatnic Hill Formation. These commonly are no more than a few inches thick, and only locally can they be related to a known fault. The largest vein quartz observed in the area is in the southern part of the Plainfield quadrangle (P-5.6; 9.7W). The exposed part of the vein is about 5 feet thick and 20 feet long; this probably is about the actual thickness of the vein, but it may extend beyond the exposure for some distance along strike. The vein trends about due north and dips about 65° W. The quartz is dull white, structureless and massive. The rock is almost pure quartz; the only impurity is 1 or 2 percent sericite. The thin section shows about 70 percent medium-grained quartz, mostly with smooth, angular boundaries, and about 30 percent of a matrix of very fine-grained sutured quartz. The boundaries of the medium-grained quartz are strongly sutured where in contact with the fine-grained matrix.

In both megascopic and microscopic character the quartz rock closely resembles the large, massive quartz vein at Lantern Hill in the Old Mystic quadrangle to the south. Loughlin (1912, p. 135-141) concluded that the Lantern Hill mass resulted from silicification of the nearby alaskite of the Sterling Plutonic Group, as he could trace all stages of replacement from normal alaskite through partially sericitized and silicified gneiss into quartz rock containing minor sericite. The partially silicified rock is cut by numerous veins of comb structure. Similar partially silicified alaskite, crossed by comb structured veins, is exposed about 1,000 feet south of the quartz vein in the Plainfield quadrangle. Loughlin (1912, p. 143) suggests that the source of the silica was pneumatolytic solutions from the deeper, uncrystallized parts of the Sterling magma. The vein quartz, however, must be much later than crystallization of the Sterling rocks and is probably later than cataclasis of the nearby rocks. Loughlin apparently failed to recognize the strongly faulted nature of the rocks in the Preston area. Two small faults that he shows on his map just north of Lantern Hill are along the strike of the long dimension of the quartz vein, and these faults and the vein probably connect to form a fairly large north-trending fault. All of the large quartz veins observed so far, both in the Preston area and in this area are associated with belts of quartzite of the Plainfield Formation and the silica solutions may have resulted from partial solution of the quartzite during cataclasis.

Magnetite occurs in several quartz veins which cut the tonalitic gneiss in the Quinebaug Formation in the Danielson quadrangle (D-38.7N; 10.8W). The veins are commonly about 1 inch thick and are in two sets; one set is about parallel to the foliation of the gneiss and dips about 10° NW., and the other set is along a joint set that strikes N. 80° E. and dips 75 to 90° SE. In some veins quartz is associated with fine-grained magnetite, and in places the vein is pure magnetite. The magnetite does not occur in all veins, but does occur in veins of both sets. The concentration of magnetite in the veins is not large enough to reflect on the aeromagnetic map (Philbin and Smith, 1966a).

METAMORPHISM

Regional distribution.--The rocks of eastern Connecticut were regionally metamorphosed to a medium to high grade probably during the Acadian orogeny, and the distribution of the zones of regional metamorphism, so far as they are known, are shown by red lines on plate 1. Subsequent to the peak of regional metamorphism rocks in the vicinity of the Honey Hill-Lake Char thrust fault were cataclastically deformed. Cataclasis apparently started during the waning stages of regional metamorphism, when the area was still warm enough for garnet, biotite and amphiboles to recrystallize, and continued over a long period of time. During the late stages of cataclasis some rocks were retrogressively metamorphosed to low grade assemblages of chlorite, sericite and calcite.

The lowest grade of regional metamorphism recognized in eastern Connecticut is staurolite-kyanite, and rocks of this grade are the youngest rocks of the area in the cores of major synclines. These include primarily the Bolton Group of Rodgers et al (1959) in the Great Hill syncline on the west, and the Scotland Schist and Hebron Formation in the Hampton syncline in the Plainfield-Danielson area and adjacent quadrangles north and south. Metamorphic minerals and mineral assemblages typical of lower grades have been suggested in the area, but none have been proven. In the Fitchville quadrangle, Snyder (1964a) suggested a local garnet zone in the Scotland Schist where no staurolite was observed. Local areas of Scotland Schist without staurolite are, however, fairly common, and it seems likely that the absence of staurolite in the Fitchville quadrangle is related to the composition of the rock rather than to lower temperatures. Andalusite was reported by Sohon (1951, p. 8) from several towns in eastern Connecticut, but none of these occurrences could be substantiated. For most of the localities (Norwich, Thompson, Union and Chaplin) he cites Shepard (1837) and for others (Willimantic and Chester) he cites Dana (1899). Shepard (1837, p. 133), however, mentions only two localities of andalusite in Connecticut, both of which are west of the Triassic basin, and Dana, following Shepard, likewise cites only the same two localities. Foye (1949, p. 78) reported andalusite in the Scotland Schist north of the Shetucket River (Scotland quadrangle) near the dam. Foye's thin sections and notes are on file at Wesleyan University and a check of these revealed staurolite but no andalusite in the samples. Andalusite does occur to the north near Worchester, Massachusetts, but it is unlikely that there is any in eastern Connecticut.

The rocks in the rest of eastern Connecticut are high grade metamorphic rocks, and contain mineral assemblages typical of sillimanite and sillimanite-potassium feldspar grades. North and west of the Honey Hill-Lake Char thrust fault the high grade rocks occur in the limbs of the major synclines and in domal and anticlinal cores. South of the Honey Hill fault the isograd between sillimanite and sillimanite-potassium feldspar grade rocks crosses the Chester syncline at a high angle (Lundgren, 1964), and the core of the Hunts Brook syncline is on the high temperature side of the isograd (Lundgren, 1966a and b; Goldsmith, 1967a and b). The sillimanite-orthoclase isograd of Lundgren (1964, 1966a and b) and Goldsmith (1967a and b) is approximately equivalent to the hypersthene-cordierite isograd on the Norwich map (Snyder, 1961; personal communication, 1967). East of the Lake Char fault, in the East Killingly quadrangle, mica-quartz schists of the Plainfield Formation contain sillimanite, kyanite and staurolite, and the indications are that in the lower plate of the fault metamorphic conditions decrease in intensity toward the north.

The attitude of the isogradic surfaces beneath the ground across eastern Connecticut is not clearly understood, but they were probably folded during the refolding of the recumbent fold system. In the central part of the area (and in the recumbent limb of the Chester-Hampton syncline) sillimanite-potassium feldspar grade Brimfield Schist structurally overlies sillimanite grade Brimfield and Hebron Formation which in turn structurally overlie staurolite-kyanite grade Hebron and Scotland Schist. Lundgren (1966b) suggested that the sillimanite-potassium feldspar isogradic surface is a fairly smooth one, cutting structural and stratigraphic units from the coast area north to its emergence in the Brimfield Schist in north central eastern Connecticut. The sillimanite-potassium feldspar isograd in the Norwich quadrangle, however, is truncated by the Honey Hill fault (Snyder, 1964a) and does not cross it to connect with the isograd in the coastal area, as indicated on Lundgren's map (1966b, fig. 1). Isograds in the area north and west of the Honey Hill-Lake Char fault are not observed to cross abruptly units or structures on the ground surface; they are in fact commonly amazingly parallel to the unit trends. If the surfaces do sharply cut the structures beneath the ground, the traces on the surface should somewhere also cut the structures. In addition, if the isogradic surfaces underground are smooth and continuous, it would mean that not far below the surface all rocks, including the Hebron Formation and probably also the Scotland Schist, must be sillimanite-potassium feldspar grade, though these units are never observed in this high grade on the ground surface, and in the core of the Willimantic dome even older rocks are lower grade. It seems probable, therefore, that the isogradic surfaces underground do not sharply cut the structure, but in general are subparallel to it, and were folded during the late stage refolding of the recumbent structure.

Regional metamorphism

The zones of regional metamorphism in the Plainfield-Danielson area include staurolite-kyanite, sillimanite and sillimanite-potassium feldspar. The isograd between the staurolite-kyanite zone and the sillimanite zone traces through the Yantic Member of the Tatnic Hill Formation (plates 2, 3, and 5). Rocks west of this line, including the top of the Yantic Member, the Hebron Formation and Scotland Schist, are on the lower grade side and pelitic schists in these units contain either or both staurolite and kyanite. Another staurolite-kyanite isograd is drawn along the western edge of the Scotland and Hampton quadrangles through the Scotland Schist and Hebron. No sillimanite was observed in the Scotland within the map area, but it does occur in the Tatnic Hill on the west edge of the Hampton quadrangle (plate 3), and in Scotland Schist in the Willimantic and Spring Hill Quadrangles just west of the map area.

The sillimanite grade rocks include the rest of the Tatnic Hill Formation, the Quinebaug Formation and probably the Plainfield Formation. Mineral assemblages typical of both sillimanite and sillimanite-potassium feldspar zones occur in the Tatnic Hill Formation. The isograd between the two zones on the Scotland and Plainfield quadrangles (plates 4 and 5) is an extension of the isograd on the Norwich quadrangle (Snyder, 1961), and is based on the westernmost observed exposures containing sillimanite and potassium feldspar. It is not therefore equivalent to the isograd drawn by Lundgren (1964, 1966b) and Goldsmith (1967a and b) in the rocks south of the Honey Hill fault, as they based the line on the disappearance of muscovite rather than appearance of potassium feldspar. The isograd in the Plainfield quadrangle is an approximation at best, and it was not continued into the Danielson quadrangle. Rocks containing sillimanite and potassium feldspar with or without primary metamorphic muscovite do occur in the lower part of the Tatnic Hill Formation. Many of the rocks, however, have been cataclastically deformed and contain retrogressive muscovite produced during cataclasis. In some rocks it is possible to distinguish primary metamorphic muscovite from cataclastic generation muscovite, but in many it is not. Another complicating factor in tracing an isograd in the rocks of that area, is that the isograd has been offset by the numerous northwest trending faults.

The sillimanite-potassium feldspar zone rocks in the lower part of the Tatnic Hill Formation are apparently truncated by a thrust fault near the contact between the Tatnic Hill and the Quinebaug Formation. Rocks containing aluminum silicate minerals are not common in the Quinebaug Formation, but do occur in the Black Hill Member and as scattered lenses in the lower member. Sillimanite in these rocks is associated with primary metamorphic muscovite, and apparently all of the Quinebaug, except possibly the uppermost part, is in sillimanite-muscovite zone. If the rocks in the top of the Quinebaug are sillimanite-potassium feldspar zone, their composition is such that it does not reflect in the mineral assemblages.

Mineral assemblages in the metamorphic rocks of the area are listed in three groups in tables 16, 17, and 18. The three groups represent the two main compositional varieties of metasedimentary rocks, the micaceous schists and gneisses and the calc-silicate schists and gneisses, and the metavolcanic rocks and amphibolites.

Micaceous schists and gneisses.--Mineral assemblages in the micaceous schists and gneisses are given in table 16. These assemblages occur in the rocks of the Scotland Schist, Yantic Member and lower member of the Tatnic Hill Formation, and as lenses in the Hebron Formation and the Quinebaug Formation. Assemblages typical of the staurolite-kyanite, sillimanite and sillimanite-potassium feldspar zones are recognized in these rocks. The rocks are fairly low in CaO and Na_2O, and these components are commonly present only in plagioclase. Assemblages in the rocks can be represented by phases in the system SiO_2-Al_2O_3-FeO-MgO-K_2O-H_2O, and can be shown in a Thompson (1957) diagram in which phases in equilibrium with quartz and muscovite are projected onto the plane MgO-FeO-Al_2O_3 (fig. 9). The compositions of the various phases, in particular garnet and biotite, have not been determined. By comparison with rocks of similar composition and metamorphic grade elsewhere (as in Albee, 1965) the garnet is most likely between two-thirds and three-fourths almandite, the remainder being mostly pyrope and grossularite.

Mineral assemblages in the staurolite-kyanite grade rocks are illustrated in fig. 9a. Chlorite is a primary phase in the staurolite zone of some areas, as in northern New Hampshire, (Green, 1963; Hatch, 1963) and Vermont (Albee, 1965), but it does not appear to be a primary metamorphic mineral in this area. Chlorite is present in minor amounts in many rocks, but in all cases appears to be retrogressive after biotite or garnet.

Assemblages listed in table 16 but which do not fit within the six component diagram of fig. 9a are kyanite-staurolite-biotite-garnet and kyanite-biotite-garnet. These assemblages are not common but do occur locally in the Scotland Schist. As suggested by Thompson (1957) these assemblages may be the result of an additional component, such as CaO or MnO in the garnet, though the analytical work necessary to establish this in the above assemblages has not been done. In some of the samples, however, the kyanite-staurolite-biotite-garnet assemblage is more likely the result of local inhomogenieties in the rocks. In these samples one or two of the minerals, most commonly kyanite, are sheathed in muscovite and do not occur in close association with the others. Thus using only local areas of the thin section, the mineral associations are: kyanite-biotite and staurolite-biotite-garnet.

Mineral assemblages in the sillimanite zone are illustrated in fig. 9b. These assemblages are most common in the upper and middle part of the Tatnic Hill Formation and as lenses in the Quinebaug Formation. The association staurolite-sillimanite is not uncommon in the lower-grade part of the sillimanite zone (see Thompson, 1957; Hatch, 1963), but has not been observed in the report area although the three phase assemblage staurolite-kyanite-sillimanite occurs in a few exposures of Scotland Schist west and north of the map area.

In the lower member of the Tatnic Hill Formation are gneisses which contain associated sillimanite-muscovite-potassium feldspar, and sillimanite-potassium feldspar. The latter is mostly in the garnet-biotite gneiss unit and less commonly in the rusty weathering gneiss unit near the base of the formation, and is commonly interlayered with muscovite bearing rocks. The muscovite in some of these rocks formed as a result of recrystallization during cataclasis, and it is not always possible to distinguish late muscovite from primary metamorphic muscovite in thin section. In the Norwich quadrangle Snyder (1961) outlined a metamorphic zone based on occurrences of cordierite and of hypersthene in the gneisses of the Tatnic Hill Formation.

This zone is approximately equivalent to the disappearance of muscovite from the sillimanite-muscovite-potassium feldspar gneisses (Snyder, personal communication, 1967). Cordierite has not been observed in the Plainfield-Danielson area, but hypersthene bearing rocks occur locally in the garnet-biotite gneiss unit (sample Pl-98, table 7), and diopside is present in some of the interlayered amphibolites of this unit and the rusty weathering gneiss unit. Snyder (1961) also recorded kyanite in some rocks in the hypersthene-cordierite zone, and in the Plainfield-Danielson area kyanite is present in some rocks of the garnet-biotite gneiss and the rusty weathering gneiss. Some of the kyanite bearing rocks also contain sillimanite (sample D3-90, table 7) and others do not. The presence of kyanite in the high grade rocks may be an indication of the high pressures which subsequently resulted in cataclasis.

The major problem involved in defining the limits of the high grade zones in the Tatnic Hill Formation is apparently due to recrystallization accompanying cataclasis. Interlayered cataclastic rocks, including mortar gneiss, mylonite and blastomylonite, are most common in the rocks east of the sillimanite-potassium feldspar isograd as it is drawn on the Plainfield and Scotland maps (plates 4 and 5). Also approximately coincident with the sillimanite-potassium feldspar isograd is a change in biotite color from yellow brown to olive brown. The change is not consistent, that is olive-brown biotite is more common than yellow brown east of the line, and less common than yellow brown west of the line. The change is, however, the reverse of that observed in biotites of other areas (see Lundgren, 1966b; Engel and Engel, 1960), where color changes go from green brown to yellow brown to red brown with increasing metamorphic grade. Red-brown biotite is quite rare in the Plainfield-Danielson area, and has been observed only in a few samples of the rusty weathering gneiss at the base of the Tatnic Hill. The color change of the biotite is, therefore, probably due to recrystallization during cataclasis. Variation in the composition of the plagioclase is probably another effect of late crystallization. In the higher grade rocks which show no indication of cataclasis, plagioclase is commonly about An 40, but in the recrystallized mortar gneisses it is less calcic.

Table 16: Mineral assemblages in micaceous schists and gneisses

STAUROLITE-KYANITE ZONE
(Assemblages with quartz and muscovite)

* Oligoclase-biotite	(9)	Ty,S	Oligoclase-garnet	S
* Oligoclase-biotite-garnet	(8)	Ty,S	Oligoclase-staurolite-kyanite	Ty (1)
* Oligoclase-biotite-garnet-staurolite	(4)	Ty,S	Biotite	S
Oligoclase-biotite-garnet-staurolite-kyanite		S	Biotite-garnet	S (8)
Oligoclase-biotite-kyanite	(7)	S	Garnet	S
Oligoclase-biotite-garnet-kyanite		S	Kyanite	H
			Oligoclase-staurolite-kyanite-biotite	S (6)

SILLIMANITE ZONE
(Assemblages with quartz and muscovite)

* Oligoclase-biotite		Ty, Ts, Tbm
* Oligoclase-biotite-garnet	(4)	Ty, Ts, Tb, Tr, Tbm, Qb
Oligoclase-biotite-sillimanite	(3)	Ty, Tbm, Ts, Ql, Qb
* Oligoclase-biotite-sillimanite-garnet	(2)	Ty, Ts, Tr, Ql
Oligoclase-biotite-K feldspar	(6)	Tbm, Ts, Tb
Oligoclase-biotite-K feldspar-garnet	(5)	Tbm, Ts, Tr
Oligoclase-biotite-K feldspar-garnet-sillimanite		Ts, Tb
Oligoclase		Tbm, Tb, Tr
Oligoclase-garnet		Qb

(Assemblages with quartz, without muscovite)

Oligoclase-biotite	Tbm, Ts, Tb
Oligoclase-biotite-garnet	Ts, Tb, Tr
Oligoclase-biotite-sillimanite	Tbm, Ts
Oligoclase-biotite-sillimanite-garnet	Ts, Tb
Oligoclase-biotite-K feldspar	Tb
Oligoclase-biotite-K feldspar-garnet	Ts
Oligoclase-biotite-K feldspar-sillimanite-Garnet	Tb, Ts
Oligoclase-biotite-K feldspar-kyanite-garnet	Tb
Biotite-garnet	Tb, Ty
Oligoclase-biotite-kyanite-garnet	Tb
Andesine-biotite-hypersthene	Tb

(Assemblages without quartz or muscovite)

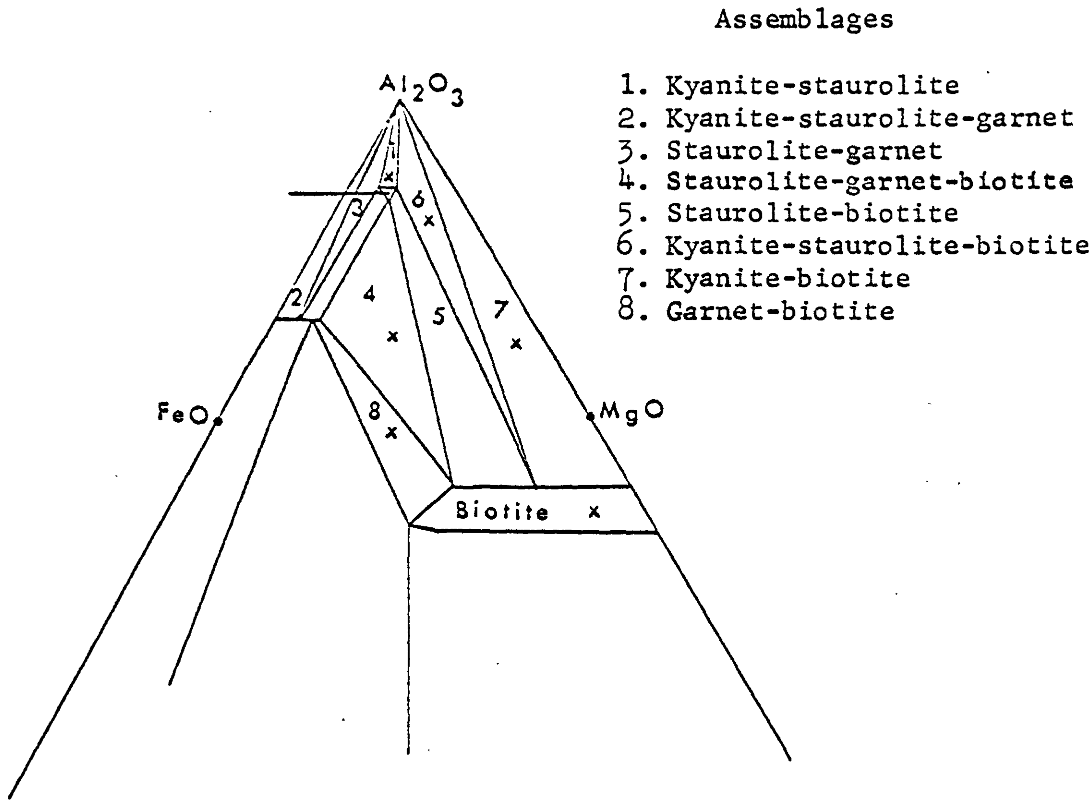
Oligoclase-biotite-garnet-kyanite-sillimanite	Tr
Biotite-kyanite	Tr

* Most common assemblages

Index to units:
S---Scotland Schist
H---Hebron Formation
Tatnic Hill Formation
Ty--Yantic Member
Tbm-biotite-muscovite schist, lower member
Ts--sillimanite schist, lower member
Tb--garnet-biotite gneiss, lower member
Tr--rusty weathering gneiss, lower member

Quinebaug Formation
Qb--Black Hill Member
Ql--lenses in lower member

Numbers refer to assemblages illustrated in Figure 14.



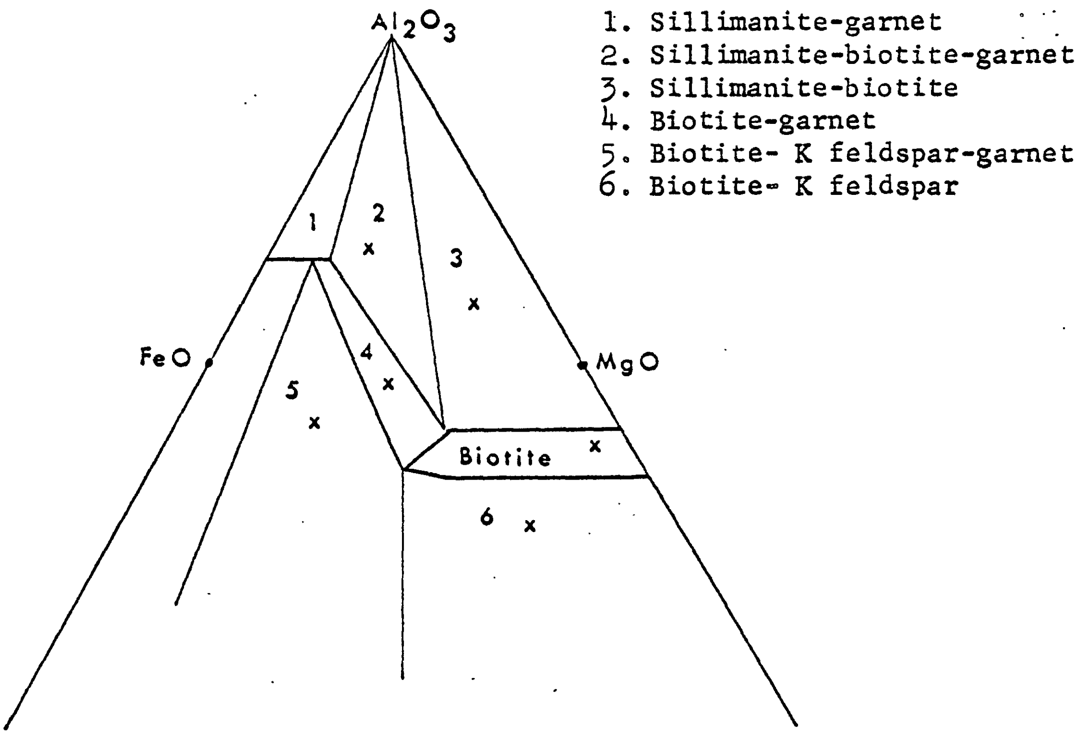


Figure 9.--Mineral assemblages with quartz and muscovite in the system SiO_2-Al_2O_3-MgO-FeO-K_2O-H_2O in eastern Connecticut. (After Thompson, 1957; plagioclase may also be present.)
(a) staurolite-kyanite zone
(b) sillimanite-muscovite zone

Calc-silicate rocks.--Mineral assemblages in the calc-silicate rocks are listed in table 17. These assemblages occur in rocks of the Hebron Formation, the Fly Pond Member of the Tatnic Hill Formation, the Black Hill Member of the Quinebaug Formation and as lenses in the lower member of the Tatnic Hill and the Scotland Schist. Compared to the micaceous gneisses these rocks are richer in CaO, FeO and MgO, and poor in K_2O and Al_2O_3. Potassium minerals such as muscovite and potassium feldspar are rare in the Hebron and Tatnic Hill rocks, but muscovite is common in the Black Hill Member. The rocks typically are composed of various combinations of biotite, amphibole, epidote and less abundantly calcite, diopside and scapolite. Actinolite is the most common amphibole. Garnet is rare in the calc-silicate rocks of this area, but may occur locally as an accessory mineral in the Hebron. Most of the garnet in the Hebron is a light yellowish brown, and is probably rich in grossularite; in some of the biotite-plagioclase-quartz schist, however, the garnet is moderate red and is probably fairly rich in almandite. In table 23 garnet is listed in the assemblages only for the rocks in which it amounts to more than 1 per cent of the sample; it may be present in almost any of the other assemblages, but only as one or two small grains in a thin section.

Most of the calc-silicate rocks are in the staurolite-kyanite and the sillimanite-muscovite grades of metamorphism, though some of the lenses in the lower Tatnic Hill may be within the sillimanite-potassium feldspar grade. The calc-silicate rocks of the Tatnic Hill Formation are all within the sillimanite grade, while those of the Hebron are primarily in staurolite-kyanite grade. There does not appear to be any distinctive difference in the mineral assemblages of the two metamorphic grades which would distinguish them. As a general rule diopside is more common in the

Table 17: Mineral assemblages in the calc-silicate rocks
(Assemblages with quartz and andesine)

STAUROLITE-KYANITE ZONE

With calcite		Without calcite	
* Biotite	H	* Biotite	H
Biotite-actinolite	H	* Biotite-actinolite	H
Actinolite-epidote	H	* Actinolite-epidote	H
Biotite-epidote	H	Biotite-epidote	H
Actinolite-epidote-diopside-scapolite	H	Actinolite-epidote-diopside-scapolite	H
		Biotite-actinolite-epidote-diopside-scapolite	H
		Epidote	H
		Actinolite	H,S
Actinolite-epidote-scapolite	H	Actinolite-epidote-scapolite	H
Biotite-actinolite-epidote-scapolite	H	Biotite-actinolite-epidote-scapolite	H
Biotite-actinolite-epidote	H	* Biotite-actinolite-epidote	H
		Biotite-scapolite	H
Biotite-muscovite-garnet	H	Biotite-muscovite-garnet	H
Biotite-muscovite	H	Biotite-muscovite	H
		Actinolite-garnet	H
Biotite-actinolite-garnet	H,S		

SILLIMANITE ZONE

With calcite		Without calcite	
		Actinolite	Tf
		Actinolite-biotite	Tf,Tc,Qb
		* Actinolite-epidote	Tf
Actinolite-biotite-epidote	Tc	* Actinolite-biotite-epidote	Tf,H,Qb
		* Actinolite-epidote-diopside	Tf
		Actinolite-epidote-biotite-diopside	Tf,H
Biotite-epidote	H,Qb	Biotite-epidote	Tf,H,Qb
Actinolite-epidote-biotite-scapolite	H	Actinolite-epidote-biotite-scapolite	H,Tc
		Actinolite-epidote-diopside-scapolite	Tc
		Actinolite-biotite-diopside	Tf,Tc
		Actinolite-diopside	H
		Actinolite-biotite-diopside-garnet	Tc
		Actinolite-epidote-diopside-garnet	Tf
		Biotite-diopside-epidote	Tc
Biotite-muscovite	Qb	Actinolite-biotite-garnet	Tc
Biotite-muscovite-epidote	Qb	Biotite-muscovite-garnet	Qb

* Most common assemblages.

Key to Units:
H---Hebron Formation
S---Lenses in Scotland Schist
Tf--Fly Pond Member of Tatnic Hill Formation
Tc--Lenses in Tatnic Hill Formation
Qb--Black Hill Member of Quinebaug Formation

sillimanite grade rocks and calcite, epidote and garnet are more abundant in the staurolite-kyanite grade rocks. These differences may, however, be the result of differences in bulk composition rather than temperature-pressure differences during crystallization. Possibly detailed mineral analyses, specifically of the biotites and hornblendes, and possibly epidotes, in rocks of the two metamorphic zones would give indications of differing temperature-pressure conditions of recrystallization.

Metavolcanic rocks and amphibolite.--Mineral assemblages in the metavolcanic rocks and amphibolites of the Quinebaug and Tatnic Hill Formations are given in table 18. These rocks have a wide variation in composition, from rocks of granitic composition through hornblende diorite and amphibolite. The majority of the rocks are rich in calcic and mafic minerals, such as biotite, hornblende, epidote and less commonly diopside. Most of the rocks of the Quinebaug Formation were probably deposited as volcanic sediments, though some perhaps were reworked volcanic rocks. A few lenses of sillimanite gneiss in the Quinebaug, of apparent sedimentary origin, have been included in table 16, and possibly some of the biotite- or muscovite-biotite-quartz-plagioclase gneiss is also of sedimentary origin. These rocks are, however, interlayered with the metavolcanic rocks on a small scale, and those of volcanic origin cannot be distinguished from those of sedimentary origin. The amphibolites are of mixed origin; those in the Quinebaug Formation are most likely of volcanic origin while at least some of those in the Tatnic Hill are of sedimentary origin. The compositions of both varieties are in general similar, except that those of sedimentary origin are more likely to contain quartz and biotite. The tonalite gneiss unit in the northern part of the Danielson quadrangle is the only mappable unit of original felsic volcanic rocks.

Table 18: Mineral assemblages in the metavolcanic rocks and amphibolites

SILLIMANITE ZONE
(Assemblages with quartz and plagioclase)

Biotite	Ql, Qu
Epidote	Qu, Ql
Hornblende	Ta
* Biotite-hornblende	Qu, Ql, Ta
* Biotite-epidote	Qu, Ql
* Biotite-hornblende-epidote	Qu, Ql
* Hornblende-epidote	Ql, Ta
Biotite-potassium feldspar	Qu, Ql
Epidote-potassium feldspar	Qu
Biotite-epidote-potassium feldspar	Ql
Hornblende-epidote-potassium feldspar	Ql
Biotite-epidote-muscovite	Ql
Biotite-hornblende-epidote-muscovite	Ql
Biotite-epidote-muscovite-garnet	Qu, Ql
Biotite-muscovite	Ql, Qg
Biotite-hornblende-garnet	Ql, Ta
Biotite-muscovite-potassium feldspar	Qg
Biotite-epidote-garnet	Ql
Biotite-garnet	Ql
Hornblende-epidote-garnet	Ql

(Assemblages without quartz)

Hornblende	Qu
Plagioclase-hornblende-epidote	Ta
Plagioclase-hornblende-biotite-epidote	Qu, Ql
Plagioclase-hornblende-epidote-potassium feldspar	Qu
Plagioclase-hornblende-diopside	Qu
Plagioclase-hornblende-epidote-anthophyllite	Ql
Biotite-hornblende-epidote-diopside-scapolite	Qu
Plagioclase-hornblende-epidote-diopside-scapolite	Qu
Plagioclase-hornblende-epidote-scapolite	Qu, Ta

* Most common assemblages.

Key to units:
Qu--upper member of the Quinebaug Formation
Ql--lower member of the Quinebaug Formation
Qg--tonalite gneiss in the Quinebaug Formation
Ta--amphibolite lenses in the Tatnic Hill Formation

The lenses of sillimanite-muscovite gneiss in the Quinebaug Formation indicate that most of the unit was metamorphosed to sillimanite grade, and all the assemblages listed in Table 18 are considered to be of sillimanite grade. Most of the rocks in the lower member of the Quinebaug and many in the upper member were cataclastically deformed subsequent to the regional metamorphism. The assemblages listed do not include those from rocks which were recrystallized during cataclasis so far as it was possible to distinguish them. Thus muscovite may occur with almost any of the assemblages listed, but is included only with those in which it appeared to be a primary metamorphic mineral. Other minerals, such as garnet, hornblende, epidote, and less abundant scapolite appear to have crystallized both during regional metamorphism and during cataclasis, and in thin section it is commonly difficult to determine which. It is possible that detailed analytical work on these minerals would show compositional differences between minerals of the two generations by which they might be distinguished.

Cataclastic deformation

Subsequent to the peak of thermal metamorphism many of the rocks in the eastern half and locally some in the western part of the Plainfield-Danielson area were cataclastically deformed. Cataclasis is related primarily to movement on the Lake Char thrust fault and on smaller thrust faults in the upper plate and, less commonly, the lower plate of the Lake Char fault. The rocks most commonly and most strongly affected by cataclasis include the Sterling Plutonic Group, the Plainfield Formation, Quinebaug Formation and the lower member of the Tatnic Hill Formation; local areas of cataclasis are observed in the upper part of the Tatnic

Hill, the Hebron Formation, Scotland Schist and Canterbury Gneiss.

The mineralogy and fabric of the cataclastic rocks vary considerably depending on the composition of the original rock, on the degree of granulation, and on the degree of recrystallization and of neomineralization during cataclasis. The mineral assemblages of the cataclastic rocks, with the exception of those which have been strongly neomineralized, are typical of sillimanite grade rocks, but the textures are not. The noncataclastic rocks of the area are commonly granoblastic schists and gneisses having a fairly uniform grain size which averages 0.5 to 1 mm diameter. Grain boundaries are smooth and angular or slightly rounded, depending on the mineral. Quartz grains may show weak undulose extinction, but it is not prominent, and the grain boundaries are smooth, not sutured. Plagioclase grains are not zoned, are not perthitic, and show simple twinning, most commonly albite and pericline (plate 7, fig. 1; pl. 9, fig. 1 and 2; plate 12, fig. 1).

In megascopic appearance the cataclastic rocks are commonly darker and more thinly laminated than the corresponding noncataclastic rock. Cataclastic rocks poor in mafic minerals, such as alaskite or quartzite, are about the same color as the noncataclastic variety, or are pale green or pink. Fine scale lamination is seen in many of the mylonites, though in some, especially some of the mylonite gneisses which resulted from granulation of originally massive rocks, little or no lamination is seen across several feet of rock. The cataclastic rocks are typically very hard, tough and difficult to break with a hammer. They break first along fracture surfaces of the rock, and further breakage is as thin concoidal flakes, rather than along lamination or foliation planes.

Examples of progressive granulation of various rocks are illustrated in the photomicrographs of plate 7, 8 (Plainfield Formation), 9, 10, 11 (Tatnic Hill Formation), 12 (alaskite gneiss of the Sterling Plutonic Group), and 13 (lower member of the Quinebaug Formation). Details of some features of the cataclastic rocks are shown in plates 14, 15, 16, and 17.

Cataclastic breakdown of the rock is commonly reflected first in the quartz grains. Quartz may show any or all of: (1) reduction of moderate size grains to streaks of very-fine grains or to a very-fine-grained matrix, (2) increase in intensity of undulose extinction, (3) increase in complexity of suturing of grain boundaries, and (4) elongation of grains. In the mortar gneisses, quartz grains are variable in size from very-fine grained to the moderate to coarse grain seen in non-cataclastic rocks (pl. 10, fig. 1 and 2). With increasing intensity of granulation, all quartz grains are very fine grained. Recrystallization of quartz during cataclasis is indicated both by elongation of the grains in some rocks and more commonly by suturing of quartz boundaries. Inducement of strong undulose extinction in the grains apparently preceded breakage and recrystallization. In plate 17, figures 1 and 2 the aggregate of grains enclosed in the circle probably represent one original grain which was about 0.5 mm diameter. Recrystallization and suturing took place within the grain as it fractured as well as along the edges of the grain. The sharp line of extinction around some grains is the result of interference of overlapping grains. In some of the cataclastic rocks quartz grains were granulated with little or no recrystallization, resulting in fairly angular grains (pl. 10, fig. 3 and 4), but more commonly the quartz is sutured, and the degree of suturing in general increases with the degree of cataclasis (pl. 7, fig. 4; pl. 8; pl. 11; pl. 17, fig. 1, 2, and 3). Elongation of the quartz grains is most commonly observed in cataclastic quartzite and quartz rich schist (pl. 7, fig. 2 and 3; pl. 8, fig. 3 and 4; pl. 17, fig. 4). Quartz inclusions in poikilitic grains, such as garnet and hornblende, commonly show smooth boundaries and a lack of undulose extinction, in contrast to the quartz in the groundmass of the cataclastic rock (pl. 15, fig. 4).

The breakdown of biotite apparently started soon after that of quartz. Biotite is comminuted either to streaks of very-fine-grained biotite with quartz (pl. 9, fig. 3 and 4; pl. 10, fig. 1 and 2) or to a very-fine-grained network in the rock matrix (pl. 10, fig. 3 and 4; pl. 15, fig. 1 and 2; pl. 16). Most of the biotite probably recrystallized during granulation. This is suggested by color variations in the biotite and by the scarcity of bent flakes or kink bands. The color of the biotite in the cataclastic rocks varies from yellow brown (typical of the non-cataclastic gneisses) to olive brown to green, and in many rocks the color is variable within a thin section. The green biotite of the cataclastic rocks is distinguished from chlorite only by the high birefringence. Minor amounts of chlorite occur with the biotite in many of the cataclastic rocks, and in the blastomylonites almost all biotite is altered to chlorite.

Most of the cataclastic rocks in the Plainfield-Danielson area contained little or no muscovite prior to cataclasis, either because of grade of metamorphism or because of composition. Muscovite which is present in many of them now is apparently the result of recrystallization during cataclasis. Lundgren (1963) describes augen of bent muscovite flakes in the blastomylonites along the Honey Hill fault and bent muscovite does occur in some rocks of the Quinebaug Formation. This suggests muscovite is fairly resistant to granulation.

Amphiboles are moderately resistant to cataclasis. The grains do not break along cleavage planes, but rather are ground off along grain boundaries (plate 13, fig. 1 and 2; plate 14; plate 15, fig. 4). Thus the edges of the grains become ragged and irregular and grains become progressively smaller with increasing intensity of granulation. Fine-grained euhedral amphibole in some of the cataclastic rocks suggests that some amphibole recrystallized during cataclasis (plate 13, fig. 3; plate 17, fig. 4). The ground off fragments of the amphibole grains are commonly neomineralized to epidote, actinolite, chlorite and sphene. In the blastomylonites (plate 13, fig. 4) all amphibole is neomineralized to chlorite, epidote and sphene.

The feldspars are the most resistant to granulation of the common rocks forming minerals, and potassium feldspar is more resistant than plagioclase. As with the amphiboles, the feldspars do not commonly break along cleavage planes, and only in the most strongly cataclastic rocks are the grains fractured and broken. Plagioclase grains in many cataclastic rocks are ground off along grain boundaries and the fragments mixed with fine-grained quartz are strung out from the core grains (plate 11). In the mylonite gneisses porphyroclasts of both plagioclase and potassium feldspar may be broken and the fractures filled with very-fine-grained quartz and feldspar (plate 16). The Carlsbad twin plane in the potassium feldspar porphyroclasts is commonly a plane of fracture filled with very-fine-grained quartz and feldspar (plate 12, fig. 4; plate 16, fig. 3). Compositional changes in the plagioclase during cataclasis are indicated by several factors: (1) exsolution of potassium feldspar as fine grains in or adjacent to the plagioclase grains, rarely as perthitic lamellae,

(2) rounded blebs of quartz included in the plagioclase grain (quartz inclusions in plagioclase in noncataclastic rocks are commonly angular), (3) epidote, sericite, and muscovite in plagioclase and small epidote grains around the edges of the plagioclase grains, (4) zoning of grains of moderate to coarse size (plate 13, fig. 1), and a variation in composition from andesine to almost pure albite within a given thin section. Thus the plagioclase loses the potassium and calcium components and trends in composition toward albite. Potassium feldspar grains in the mylonite gneisses also show exsolved plagioclase in irregular, wavy streaks (plate 16, fig. 2 and 4). Plagioclase grains in many of the cataclastic rocks show complex twinning, in contrast to the simple twinning in the pagioclase of noncataclastic rocks. Broken plagioclase grains, with bent twin lamellae, are not common, but are seen in some rocks (plate 10, fig. 1 and 2; plate 16, fig. 4).

Garnet is also strongly resistant to granulation, although its resistance is variable. Indications of broken grains (plate 11, fig. 3 and 4) or of granulation along the grain boundaries are rare. More commonly euhedral garnet grains with little or no suggestion of breakage occur in a fine-grained cataclastic matrix (plate 15, fig. 1 and 2), or garnet grains are partially to completely pseudomorphed by chlorite and sericite (plate 10, fig. 3 and 4). Some garnet apparently grew during cataclasis. In the cataclastic rocks of the Quinebaug Formation, euhedral garnet grains occur locally in the plane of cataclastic foliation, and must have grown during cataclasis.

The sequence from noncataclastic rock to mylonite differs somewhat depending on the rock. In most rocks incipient mylonitization is shown in the mortar gneisses as discontinuous streaks of very-fine-grained minerals, primarily quartz and biotite, between bands of ungranulated minerals (plate 10, fig. 1 and 2). The partially granulated rocks typically show and extreme variation in grain size. As the degree of granulation increases and the rocks become mylonite gneisses, the streaks merge to form a matrix for the ungranulated grains, mainly feldspars, hornblende, garnet and in some rocks sillimanite (plate 9, fig. 3 and 4; plate 11; plate 12, fig. 2 and 4; plate 14; plate 15). The mylonites are thoroughly granulated to a very-fine-grained rock with a few slightly coarser grains of feldspar or garnet (plate 10, fig. 3 and 4; plate 12, fig. 3). In most of the mylonite gneisses and mylonites, quartz and feldspar in the matrix are so fine grained that they cannot be distinguished without staining the thin section. Monomineralic rocks, as quartzite, show progressive diminution in grain size with increasing granulation, rather than streaks of granulated minerals (plate 7).

Cataclastic deformation was accompanied by growth of new minerals, recrystallization of pre-existing minerals with little or no change in composition, and neomineralization of pre-existing minerals to form new minerals. Growth of new minerals (mainly garnet and some amphibole) and recrystallization of quartz, biotite and amphibole probably took place in the early stage of cataclasis while the area was still fairly hot. As the area cooled, recrystallization involved greater changes in the composition of the minerals resulting in the green biotites, actinolitic amphibole, exsolution of potassium feldspar from plagioclase, and breakdown of the plagioclase to epidote, quartz, and a more sodic plagioclase. Neomineralization and the formation of blastomylonites took place late in the cataclastic deformation, and was apparently controlled by the availability of water. Neomineralization resulted in formation of chlorite from biotite, epidote, chlorite, sphene and probably calcite from hornblende, sericite, muscovite, epidote, quartz and calcite from plagioclase, sericite and muscovite from potassium feldspar, and sericite and chlorite from garnet. Completely neomineralized blastomylonites are rare, and are observed only adjacent to the fault planes, along which water could have moved. In plate 13, sample P2-381 in fig. 4 was collected a few inches above the exposed Lake Char fault plane, PN65-A about a foot above the fault plane, and PN65-B about 3 feet above the fault. Sample P2-381 is almost completely neomineralized, while PN65-A and B show very minor neomineralization, although in PN65-A hornblende has almost completely recrystallized to an actinolitic amphibole. It is possible the neomineralization was a late hydrothermal alteration rather than accompanying late stage cataclasis, but this does not seem likely. Rocks along the strong fracture system close to the fault plane are not strongly neomineralized, and there is no indication that hydrothermal solutions moved along these fractures.

Cataclasis and accompanying recrystallization apparently took place with little or no change in the chemical composition of the rocks. This is suggested by comparison of the chemical analyses of the cataclastic and noncataclastic alaskite of the Sterling Plutonic Group in table 21. The cataclastic rocks are almost directly comparable in composition to the noncataclastic rocks. Similar comparisons cannot be made of the rocks of the Quinebaug Formation and the correlative Monson Gneiss, as there is too wide a variation in the compositions of these rocks. The blastomylonitic rocks must, however, have had some change in chemical composition, if only the addition of water. On the basis of chemical analyses of what he considers to be comparable rocks, Bryant (1966) argues for loss of Ca and Na and gain of K and probably Fe during phyllonitization of the gneiss in the Grandfather Mountain Window area of North Carolina. A blastomylonite of the Quinebaug Formation (sample Pl-212, table 3) is the most completely neomineralized rock which was analysed, and the analysis suggests a loss of CaO and possibly Na_2O, but there is no suggestion of an increase in K_2O nor of FeO.

STRUCTURAL GEOLOGY

Evidences of strong deformation are abundant in the Plainfield-Danielson area. All the rocks except a few small pegmatites and the small gabbro sill are well foliated, and many contain two foliation planes. One direction of lineation can be seen in most rocks, and in many rocks there are two directions. The lineations are formed by orientation of elongate minerals, streaks of mineral grains, intersection of S planes and crinkles. Small folds, with amplitudes of a few feet or less, are common throughout the area; larger folds with amplitudes of tens to hundreds of feet can be mapped out in some places. The crinkle lineations are the axes of the smallest folds of the area. Faults, some with observable offsets of a few feet or less and others with undetermined offset, can be observed in outcrop, and larger faults, with probable offsets of hundreds of feet can be mapped out. Other small scale features, such as boudins, some of which have been stacked up, and rotated pods or mineral grains can be observed locally.

The two major structural features of the Plainfield-Danielson area are the Lake Char thrust fault and the recumbent Hampton syncline, both of which are parts of large, regional structures of eastern Connecticut. The Lake Char fault traces across the eastern edge of the area; it continues southward to the Preston Gabbro where it is continuous with the Honey Hill fault, and northward into Massachusetts. The trace of the axial plane of the Hampton syncline goes through the northwestern part of the area, and is continuous with the Chester-Hunts Brook syncline around the Willimantic dome to the southwest (see pl. 1; fig. 2). Emplacement of the Hampton syncline into its present position must have involved at least two stages of folding. During the early stage the rocks were folded into the major folds of eastern Connecticut, including the Hampton syncline. The second stage of folding involved refolding and overturning from west to east of the early folds (see fence diagram, pl. 1). The axial surface of the recumbent syncline is now subparallel to the plane of the Lake Char-Honey Hill fault, and the direction of movement of refolding and overturning of the syncline is about the same as the direction of movement on the thrust fault. It is possible that refolding of the early folds was about contemporaneous with movement on the thrust fault. Many of the small structures of the area, including strong regional foliation, the common north-trending lineations, some small folds and rotated pods and minerals may reflect the west to east movement of the refolding of the syncline and of the thrust faults.

FAULTS

A complex system of northeast-trending thrust faults offset by northwest-trending high-angle faults has been mapped in the Plainfield-Danielson area. The major fault is the Lake Char thrust fault across the eastern edge of the area, which has been traced by mapping and reconnaissance from southern Massachusetts south to the Preston Gabbro where it connects with the Honey Hill fault (pl. 1; Lundgren et al, 1958). The Lake Char and Honey Hill thus form one large thrust fault which underlies most of eastern Connecticut. In the center of the Plainfield quadrangle (pl. 4) the Lake Char fault splits into two branches. The Honey Hill fault also splits into two branches in the Uncasville quadrangle west of the Preston Gabbro (Goldsmith, 1967a)[1/], and reconnaissance

---

1/ There is apparently a compilation error on the Uncasville quadrangle map. The split in the fault is shown within the Quinebaug Formation, so that Quinebaug occurs both north and south of the southern branch of the fault. Goldsmith (personal communication, 1966) has stated, however, that the Quinebaug Formation occurs only north of the fault; not south of it. The southern branch of the fault, therefore, should probably be located along the contact between the Quinebaug Formation and the Monson Gneiss, and it is located there on plate 1.

---

around the gabbro indicates that the two branches on the Lake Char-Honey Hill fault go above and below the gabbro; the major displacement is apparently on the lower branch which puts Quinebaug Formation and gabbro over Plainfield Formation and Sterling Plutonic Group. Throughout the length of the Lake Char fault as it has been mapped so far, the trend of the fault is parallel to the structural trend of the rocks on either side, and the fault is recognized primarily by cataclasis of the rocks which is most intense at the contact of the Quinebaug Formation and the gneisses of the Sterling Plutonic Group.

In addition to the Lake Char fault there are in the area a number of smaller faults, both low-angle thrust faults and high-angle faults. Faulting and cataclasis are much more extensive in the rocks of the upper plate of the Lake Char fault than in the lower plate. The faults range from very small ones which cannot be traced beyond a given outcrop and which have displacements of a few inches or less to large ones which can be traced across several quadrangles and have probable displacements of thousands of feet. Cataclasis is associated primarily with the thrust faults, and was only locally observed adjacent to the high-angle faults. Evidences of faulting, such as slickensided surfaces, small faults with minor offset observable in outcrop, drag folds, quartz veins and less commonly ultramylonite dikes can be observed throughout the area, but are most abundant in the lower member of the Tatnic Hill Formation and the Quinebaug Formation; only locally can they be related to a large, adjacent fault.

Thrust faults

Lake Chargoggagoggmanchauggagoggchaubunagungamaugg Fault.--The Lake Char fault forms the contact between the Quinebaug Formation in the upper plate and the Sterling Plutonic Group and included lenses of Plainfield Formation in the lower plate. The fault trends generally north or north-northeast across the Plainfield and Danielson quadrangles, and dips west at a low angle. The fault contact between the Quinebaug and Hope Valley Alaskite is exposed in two places in the Plainfield quadrangle. One exposure is on the east slope of the long hill west of Starkweather Road (P-24.5-25N; 5-5.5W), and the other is in the northeastern corner of the quadrangle (P-43N; 0.7W). At both localities the fault contact dips west about 10°, although it is warped, or slightly folded. Elsewhere in the area the cataclastic rocks bordering the fault dip about 20° to 30° west, except where steepened by late folding or faulting, and the general dip of the fault plane is probably about 25° west.

Movement on the Lake Char fault plane was apparently from northwest to southeast. The primary indication of movement direction in the Plainfield-Danielson area is a pervasive N. 60°-70° W. lineation in the cataclastic rocks adjacent to the fault. The lineation is formed by streaks of granulated mineral grains. It is probably an <u>a</u> lineation produced by stringing out of the granulated minerals parallel to the direction of movement. The lineations plunge northwest at a low angle, although in the upper plate of the fault they are locally reversed, probably by drag, and plunge southeast. Figure 10 is a stereographic plot of 60 observed lineations close to the fault. The <u>a</u> maximum plunges 10° N. 60° W.. The direction of plunge, however, shifts from about N. 55° W. in the southern part of the Plainfield quadrangle to about N. 75° W. in the northern part of the Danielson quadrangle. The lineations do not indicate whether movement of the upper plate was towards the southeast or the northwest, but the former is consistent with the eastward movement on the Honey Hill fault.

The amount of movement on the Lake Char fault plane cannot be determined, and within the Plainfield-Danielson area no actual displacement can be proven. The Quinebaug Formation has not been observed in an area where it is not faulted, so it is impossible to determine how

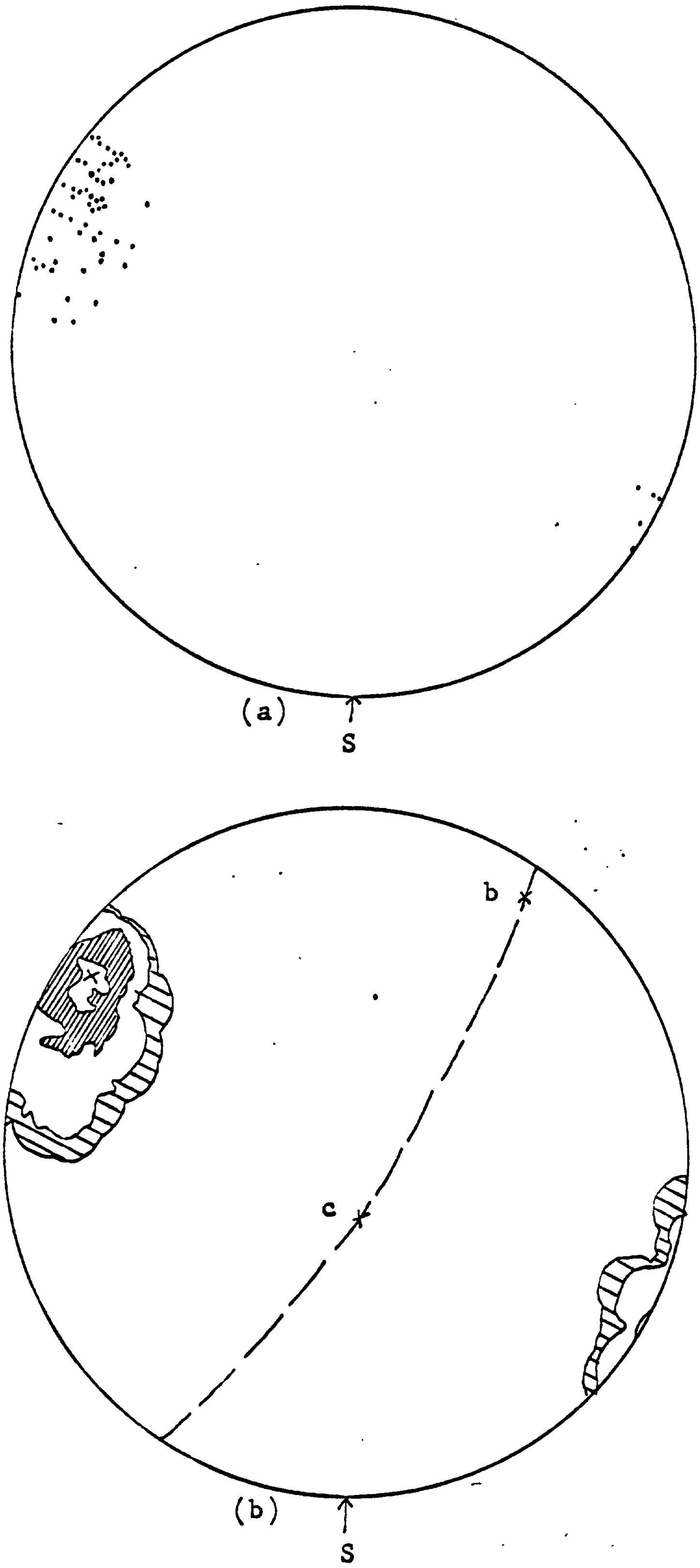


Figure 10.--Cataclastic lineation in mylonites adjacent to the Lake Char fault. Points are plotted on the lower hemisphere of an equal area net.

(a) Plot of the lineations.

(b) Contour diagram; contour intervals 1.6, 5, 15, 33% per 1% area. X represents the <u>a</u> maximum at 10° N. 60° W.

much of the unit has been cut out by the fault. The fault apparently cuts across the Quinebaug Formation at a low angle to the north. The unit thins from about 7,000 feet thick in the southern part of the Plainfield quadrangle to about 3,000 feet thick in the northern part of the Danielson quadrangle. It is possible, however, that the difference in thickness is due to original depositional differences, and within the Plainfield-Danielson area the only indication that this is not the case is cataclasis of the rocks. Preliminary mapping and reconnaissance to the north suggest that truncation of the Quinebaug Formation continues, so that west of Lake Chargoggagoggmanchauggagoggchaubunagungamaugg in southern Massachusetts the unit is very thin and north of the lake it is apparently cut out entirely.

Stratigraphic discordance between the upper and lower plate of the fault also cannot be demonstrated within the Plainfield-Danielson area. The Plainfield Formation in the lower plate of the fault in this area is probably near the top of the unit (G. Moore, personal communication, 1966). To the southwest the Monson Gneiss, correlative with the Quinebaug Formation, is separated from the Plainfield Formation by the New London Gneiss and the Mamacoke Formation which together have a maximum estimated thickness of about 2,500 feet (Goldsmith, 1966). These units, however, lens out along strike to the east and in the Uncasville quadrangle (Goldsmith, 1967a) Monson Gneiss directly overlies Plainfield. It is possible, therefore, that rocks equivalent to the New London and Mamacoke were never present in the Plainfield-Danielson area and the sequence of Quinebaug Formation over Plainfield Formation could be a normal, stratigraphic sequence.

Because the fault does not sharply truncate units on either side, the primary evidence for a fault is cataclasis of the rocks which increases in intensity toward the fault contact. A zone of rock several hundred feet thick on either side of the fault contact has been converted to mylonite, mylonite gneiss and blastomylonite. The thickness of this zone is variable, but is considerably greater in the upper plate than in the lower plate. In addition several thousand of feet of rock in the upper plate, including most of the Quinebaug Formation and the lower member of the Tatnic Hill Formation, were cataclastically deformed to varying degrees. Within the mylonitized zone near the fault all rocks have been granulated, including late, discordant pegmatites. The contact between the pegmatite and the host rock is, however, commonly an undisturbed, intrusive looking contact, with little indication of shearing. This can be observed in the road cuts along the exit from the Connecticut turnpike at Plainfield (P-21.6N; 9.7W). The contact of the two feldspar gneiss in the lower member of the Quinebaug Formation is also locally a normal, intrusive appearing contact, with small apophyses of gneiss cutting across the layering of the surrounding hornblende and biotite gneisses or feathering out between layers. Both the two feldspar gneiss and the Quinebaug Gneiss it cuts are, however, mylonitic. Apparently, although stresses were such as to thoroughly granulate the rock, movement must have been concentrated along discrete planes, and movement within the granulated rock was no more than can be seen microscopically.

Other evidences of faulting, such as ultramylonite dikes, fault breccia, slickensided surfaces, quartz veins, and closely spaced fractures are common in zone of the Lake Char fault. Most of them, however, reflect either late stage movement on the thrust fault or on other faults, most commonly high-angle faults, concentrated in the zone of the Lake Char fault. The ultramylonite dikes and some fault breccia are associated with the Lake

Char fault or with subsidiary faults close to it, but the other features probably relate primarily to high-angle faults.

Fault breccia is probably more common in the zone of the Lake Char fault than is indicated by exposures, as these rocks are easily eroded. Only one exposure of a real breccia, consisting of angular fragments in an unconsolidated, clayey matrix, was observed in a new road cut on the Danielson exit from the Connecticut turnpike (D-14.5N; 0.5W), and the breccia could not be traced beyond the cut. The breccia is formed along a subsidiary thrust fault between the Plainfield Formation and biotite gneiss of the Sterling Plutonic Group in the lower plate of the Lake Char fault. The breccia contains clasts of mylonitized quartzite and biotite gneiss in a matrix of quartz, sericite-muscovite, chlorite and unidentified clay. The clasts may be as much as several inches in diameter. The exposure contains numerous fractures lined with drusy quartz. Other breccia areas are suggested by some of the water wells in the area, but most of them appear to be related to high-angle faulting rather than to the Lake Char fault itself.

Numerous ultramylonite dikes also were observed only at one locality on or very close to the Lake Char fault. A gravel quarry in the south-eastern corner of the Danielson quadrangle (D-3.2N; 1.5W) has been worked down to the bedrock floor, and a number of large blocks of mylonite of Quinebaug Formation and of Hope Valley Alaskite protrude from the quarry floor. Many of these are boulders, although some are probably attached bedrock, and it is apparent that none of the boulders have been moved very far. The mylonites contain abundant, very-dark-gray to black, aphanitic ultramylonite either as discordant dikes or concordant sills as much as 1 inch thick and commonly 1/4 to 1/2 inch thick. Some of the ultramylonite shows gradational boundaries with the enclosing mylonite, and some has sharp boundaries which cut across the cataclastic foliation of the enclosing mylonite.

Formation of mylonites, with accompanying recrystallization of some minerals must have taken place at depth under conditions of high pressure and moderately high temperature. The blastomylonites, which occur within inches of the fault plane require lower pressure and temperature conditions, as the minerals present are lower temperature phases, and the availability of water. The fault breccia and ultramylonites suggest low confining pressure and temperature and they occur in rocks which had been previously cataclastically deformed. The indications are, therefore, that the fault zone was active over a long period of time. Movement associated with cataclasis of the rocks probably started during late stages of regional metamorphism of the area and while the rocks affected were still deeply buried. Blastomylonite, ultramylonite and breccia formed during later stages of faulting, while the rocks were being uplifted and confining pressures were less. In addition to late movement on the Lake Char fault, and associated thrust faults, the high-angle faults of the area apparently formed during uplift.

Other thrust faults.--A number of subsidiary thrust faults occur in the upper plate and, less commonly the lower plate of the Lake Char fault. Those in the lower plate appear to be restricted to the uppermost few hundred feet below the fault. In the upper plate they are most abundant and closely spaced in the Quinebaug Formation and the lower member of the Tatnic Hill Formation, but they may occur in any of the rocks. The faults in general are subparallel to the Lake Char fault and probably formed in response to the same stress system that caused the Lake Char fault.

Abundant thrust faults are most readily demonstrated in the lower member of the Tatnic Hill Formation where cataclastic rocks can be related to repetitions of the lithologic units of the member. The stratigraphic sequence of sillimanite gneiss over garnet-biotite gneiss over rusty weathering gneiss is quite consistent in the slices between the faults, although all three units are not always present. The uniformity of the sequence and the cataclasis of the rocks near the base of each repetition, suggests the repetitions are caused by thrust faulting rather than original heterogeneity of the rocks. Many of the repeated sequences have the rusty weathering gneiss at the base. This rock commonly contains graphite, and may have been more susceptible to movement than the other rocks. Similar thrust faults are undoubtedly equally common in the Quinebaug Formation but they are more difficult to demonstrate as exposures are less abundant in the Quinebaug than in the Tatnic Hill, and it has not been possible to work out a stratigraphic sequence of lithologic types in the Quinebaug. The major evidence within the Quinebaug for thrust faults is the abundance of cataclastic rocks throughout the unit.

The amount of offset on these subsidiary thrust faults is difficult to determine, but is probably no more than hundreds of feet on most of them. Offset on the fault, or series of faults, along and below the contact between the Quinebaug and the Tatnic Hill Formations may have considerably more, however, as the indications are that near this contact high-grade metamorphic rocks (sillimanite + potassium feldspar) overlie lower-grade rocks (sillimanite + muscovite). The shape of the isogradic surface in this area is not known, but there is no evidence to indicate it dips eastward against the trend of the west dipping rock units. In the northern part of the Danielson quadrangle, the belt of high-grade rocks is apparently no more than two or three thousand feet wide, and if the isogradic surface does cut across the structures, it would have the configuration of a long narrow north-trending ridge across the Plainfield and Danielson quadrangles, and, on the basis of preliminary work, across the Putnam quadrangle also. It seems more likely that the isogradic surface here is a thrust fault. The lower-grade rocks of the Quinebaug Formation in the southern part of the Plainfield quadrangle project southwest into an area in the Norwich quadrangle where Snyder (1961) shows an increase in metamorphic grade above sillimanite + potassium feldspar. The isogradic surfaces must, therefore, either be faulted, or in the Jewett City quadrangle the trace on the surface must bend abruptly and cut across the units, which it has not been observed to do elsewhere.

The attitude of the subsidiary thrust faults in the Quinebaug and Tatnic Hill Formations is generally parallel to the Lake Char-Honey Hill fault surface, and the faults probably branch off the Honey Hill fault to the south. Snyder (1961) did not show thrust faults branching off the Honey Hill fault in the Norwich quadrangle, but their presence can be inferred by the irregular distribution of the lithologic units on his map and by the numerous exposures of mylonite in the lower member of the Tatnic Hill Formation (his Putnam Gneiss) shown on the map.

Ultramylonite dikes and associated cataclastic rocks occur locally in the Hebron Formation and the Scotland Schist. The only occurrence observed within the Plainfield-Danielson area is in the Hebron Formation in the northwestern corner of the Hampton quadrangle (H-41.7N; 27.0W). The cataclastic rocks here are close to the contact with the Eastford Gneiss. Two exposures of cataclastic rocks cut by numerous ultramylonite dikes occur in the Eastford quadrangle 500 to 1,000 feet north of the boundary with the Hampton quadrangle. One is in Still Brook at Phoenixville, and the other is about three quarters of a mile west of the first, in Bigelow Brook. The Phoenixville exposures are also close to the contact between Hebron Formation and Eastford Gneiss, and this contact locally may be a thrust fault. About a mile north of Phoenixville, however, outcrops of Eastford Gneiss and Hebron are within a foot or two of the contact, and no indication of cataclasis was observed in either rock, so the contact is not everywhere a fault.

Other local exposures of ultramylonite dikes and cataclastic Hebron Formation and Scotland Schist have been observed in the Putnam quadrangle in rocks near the axial zone of the Hampton syncline and in the overturned limb. Fault movement indicated by the cataclasis may have been related to the west to east movement of the overturned limb of the Hampton syncline. Offset and shearing of the folds in the Hebron Formation near the axial zone of the syncline are exposed in a railroad cut in the Hampton quadrangle (H-26.0N; 16.4W), although the rocks here do not appear to be cataclastically deformed.

High-angle faults

A network of high-angle faults has disrupted the rocks in the upper plate of the Lake Char fault and to a lesser extent those in the lower plate. The most abundant, or at least most prominent of these is a system of northwest-trending faults; less common are north-northeast-trending high-angle faults which are approximately parallel to the thrust faults. The high-angle faults were later than and offset the thrust faults. The northwest-trending faults have been shown on the Plainfield and Danielson maps (pl. 4 and 2) as branching off the Lake Char fault. There is a suggestion on the aeromagnetic maps, however, (Boynton and Smith, 1965~~a~~b; Philbin and Smith, 1966a) that at least some of the northwest faults may cut and offset the Lake Char fault, and they have been shown this way on the compilation map (pl. 6). They apparently do not extend very far into the lower plate, but there is some evidence that the upper part of the lower plate is strongly fractured and faulted to some extent. Similar high-angle faults have been mapped in the vicinity of the Preston Gabbro (Loughlin, 1912; Sclar, 1958), and some of these are shown as offsetting the Lake Char and Honey Hill fault.

None of the large northwest-trending faults are exposed, and they have been mapped primarily on the coincidence of (1) offset of geologic units, (2) topographic trends, and (3) offset of the trends of magnetic anomalies on the aeromagnetic maps. The geologic offsets across some of the faults could, perhaps, be the result of folding as well as faulting. The offsets occur, however, along northwest-trending valleys, which are oblique to the axial trends of the folds of the area; this suggests offset by faulting rather than folding. On the aeromagnetic maps the Tatnic Hill and Quinebaug Formations show as a complex series of north-northeast trending linear highs and lows. These are offset along lines which commonly coincide with the valley trends and the unit offsets, and the sense of offset of the anomalies is the same as the offset of the geologic units. The faults have been extended through the Quinebaug Formation, where exposure is scarce and topography is more controlled by thick surficial deposits than is the case in the Tatnic Hill, primarily on the basis of the offsets of the magnetic anomalies.

The displacement on most of the northwest faults was north side moved west and down. The amount of movement is impossible to determine accurately because the rocks were folded and displaced by thrust faults prior to high-angle faulting. The horizontal component of movement is commonly a few thousand feet, but on a few faults it is more than a mile. The largest faults include the one which crosses the Quinebaug River east of Canterbury village in the Plainfield quadrangle and the one which parallels Blackwells Brook in the Danielson quadrangle.

A few high-angle faults that trend northeast are shown on the Plainfield and Danielson maps (pl. 4 and 2). These are more difficult to demonstrate than the northwest faults as they essentially parallel the trends of the geologic units and of the magnetic anomalies on the aeromagnetic maps. The north-northeast faults in the Quinebaug Formation that are subparallel to the Lake Char fault are conjectural, although there is fairly strong indirect evidence for the one about a half mile west of the Lake Char fault. There is no good evidence for the one about two miles west of the Lake Char fault, and it has been eliminated from the compilation map (pl. 6).

The geologic evidence for the northeast fault close to the Lake Char fault is primarily in the area east and north of the village of Plainfield. The mylonites on the east side of the hill between the Connecticut turnpike and Starkweather road dip 10°-35° W., and grade westward into rocks that are cataclastic but are megascopically recognizable as hornblende gneiss, amphibolite and biotite gneiss. West of the turnpike mylonites similar to those to the east are again exposed and are steeply dipping to vertical. This repetition and abrupt change in dip suggests there is a fault about parallel to the turnpike here which has uplifted the mylonitic rocks on the west side and turned them up on end.

Other evidence for this northeast fault can be seen in the cuts on the Plainfield exit from the turnpike (P-21.6N; 9.7W), where numerous slickensided foliation surfaces are about parallel to the trend of the fault. Photographs of some of the rocks in the cuts are shown in figure 11. The foliation of some of the rocks here is difficult to see and is defined mainly by thin, white quartz and feldspar laminae; in other parts of the cuts there is a strong cataclastic lamination. The rocks are strongly faulted, and it is possible to measure several faults of differing attitude across a few feet of exposure. The most common fault direction, but also the one most difficult to see, is parallel to the plane of cataclastic foliation; it strikes N. 10°-40° E., and dips 50°-90° SE. Where the rocks have broken to expose the foliation surface, it is strongly slickensided. Two such slickensided surfaces are shown in figure 11a and b. The sense of movement on one plane is suggested by drag folds in the mylonite. A low angle fault cuts one of the slickensided surfaces near the bottom of the photo, and has moved it south about a foot. Figure 11c shows the top of the exposure above 11a, and the line drawn across the center of the photo is a continuation of the N. 20° E., 70° SE. slickensided surface. Figure 11d shows faults in another part of the cuts. The rock in the upper part of the photo (marked A) is the two feldspar mylonite gneiss and in the lower part (marked B) is hornblende-plagioclase mylonite. The fault contacts between A and A' and A' and B are parallel to the slickensided surfaces in figure 11a and if

Figure 11.--Photographs of cataclastic rocks at the lower member of the Quinebaug Formation along the Plainfield exit from the Connecticut turnpike (P-21.6N; 9.7W).

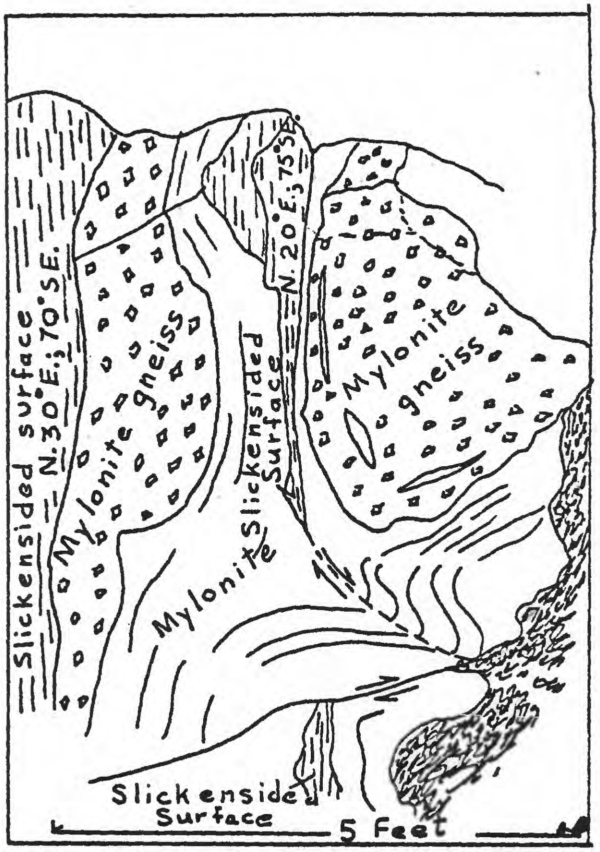
a - Mylonite and mylonite gneiss faulted along slickensided surfaces which parallel the cataclastic foliation.

b - Sketch of figure 11a showing the offset of the late faults.

c - The top of the exposure, above figure 11a. Line drawn across the picture is a continuation of the N. 20° E., 70° SE. slickensided surface in figure 11a and b.

d - Two feldspar mylonite gneiss (A and A') faulted against plagioclase mylonite gneiss (B). Lines drawn between A-A' and A'-B are faults which are subparallel to the slickensided fault surfaces.

(a)


Slickensided surface
N.30°E.; 70°SE.
Mylonite gneiss
Mylonite
Slickensided Surface
N.20°E.; 75°SE.
Mylonite gneiss
Slickensided Surface
5 Feet

(b)

(c)

(d)

the rocks were broken to reveal the contact, it also is probably slickensided. The steeply dipping slickensided surfaces in this exposure are about parallel to the projected northeast fault east of the cuts, and the sense of movement suggested by the drag in figure 11a and b, that is of west side up, is the same as the apparent movement on the larger fault.

The northeast-trending fault bordering the eastern side of the Canterbury Gneiss in the Danielson quadrangle (pl. 2) is based primarily on two faults observed in outcrop, and along both faults there is a narrow zone of cataclasis of the adjacent rock. On the hill west of Wolf Den Brook (D-34.1N; 26.4W) a fault contact between Hebron Formation and the Yantic Member of the Tatnic Hill Formation is exposed. Several feet above and below the contact both units dip about 25° NW. Near the contact the dip increases to about 60° NW., which is about the dip of the fault. The rocks one to two feet from either side of the fault contact are strongly cataclastic. The other fault is exposed in Day Brook (D-44.2N; 20.3W) and has cataclastic Hebron Formation on both sides. The fault trend here is about N. 35° E., 65°-75° NW. There is no direct evidence that these two faults connect, and they have been connected on the map primarily because they trend toward each other along a topographic low.

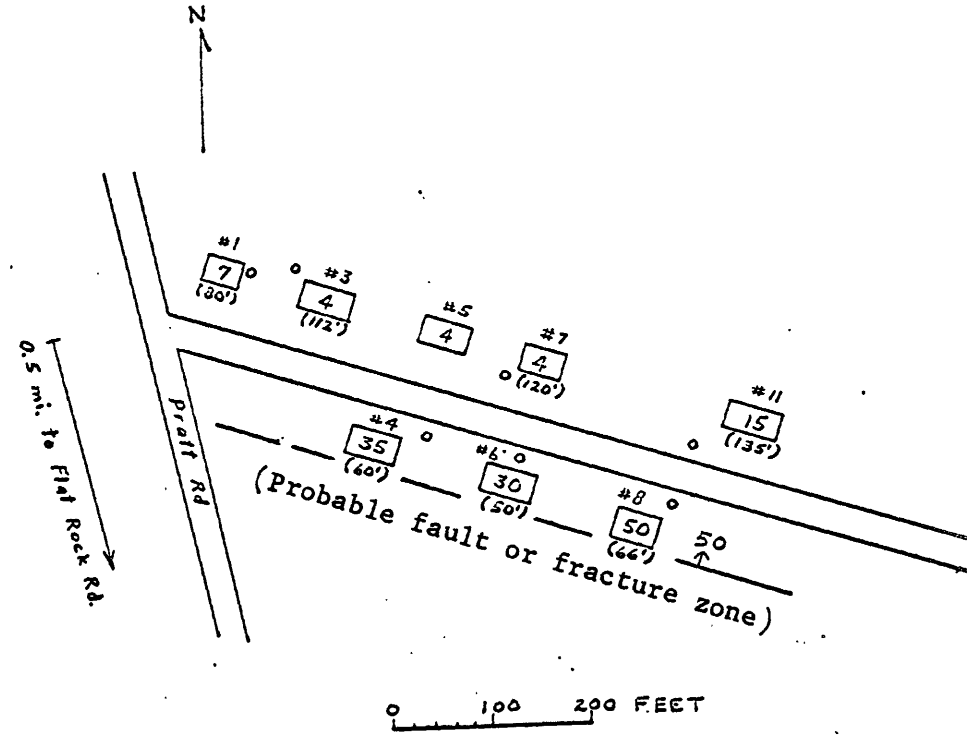
Minor faults.--Small faults of varying attitude can be observed in outcrop or inferred from indirect evidence throughout the area, but especially in the lower member of the Tatnic Hill Formation and eastward into the lower plate of the Lake Char fault. In these rocks most exposures of more than a few feet in size show at least one fault, and many show numerous small faults. Some of the faults in one large exposure are described above and illustrated in figure 11. Displacement on the faults ranges from less than an inch to probably no more than a few feet. In most cases the displacement is not enough to bring different units into juxtaposition; only where the fault is close to a contact are there different rocks on either side.

Indirect evidence for faults, breccia zones or zones of fracture comes from information on the yield of water wells in the area accumulated by Randall, Thomas and others for the Quinebaug River water study (Randall and others, 1966; Thomas and others, 1966). The information does not indicate the size or displacement of the fracture zones, although in one place the information is detailed enough to suggest the attitude of one fault.

Water wells drilled in bedrock throughout the area as a whole commonly yield less than 10 gallons per minute water. In a restricted area in the village of Moosup, Randall and others (1966, p. 63) and Thomas and others(1966, table 1) report that about half of the wells inventoried have a yield of 20 gpm or more. Similar high-yield wells are recorded by Thomas and others (1966) from several wells in or near the Lake Char fault zone, and in rocks of both the upper and the lower plate. Wells of small yield also occur within the fault zone, however, and Randall (written communication, 1963) could not trace a continuous belt of high-yield wells, although the wells are sparsely distributed in many places. The spotty distribution of abnormally high water yield from bedrock wells suggests the development of fracture zones which may be similar to the loose breccia exposed in the cut along the Danielson exit from the turnpike. At one locality Randall (written communication, 1963) was able to provide enough detail to indicate the trend and possible dip of one of the fractures. Figure 12 is a sketch of a new housing development east of Pratt Road in Plainfield (P-12N; 7.5-6.3W) and shows the location of seven new houses, the wells drilled for each, and the water yield from each well. The wells north of the road are of normal yield, while those in a line south of the road are of high yield. For the well on Lot 8, Randall provided the note, as reported by the builder: "Penetrated white, powdery granite to 60 feet, hole was dry at this depth. Then hit large chunks of brown quartz with much water.", and on Lots 9-11: "Penetrated white granite to about 70 feet, then brown quartz rocks with water". The information from these wells strongly suggests a fault or fracture zone trending about N. 75° W. and dipping steeply north. If the "brown quartz rock with water" at Lots 9-11 is the same as at Lot 8, the dip would be about 50° north, and the fault or fracture zone would project to the surface along the dashed line drawn on the sketch.

Vein quartz, commonly no more than a few inches thick, is developed along some faults and fractures. The attitude of the veins varies from vertical to horizontal. The larger veins, such as the one in the southern part of the Plainfield quadrangle described earlier, are probably along high-angle faults. Some of the veins are in fractures along which no fault movement can be demonstrated. Small, discontinuous tension fractures filled with chlorite or epidote occur locally, and are most common in the rocks close to the Lake Char fault.

The small faults observed in outcrop vary considerably in attitude and in type of displacement. The poles of the measured faults were plotted on a sterographic net and are shown in figure 13; those in the lower member of the Tatnic Hill Formation and uppermost part of the Quinebaug Formation are shown in figure 13a, and those in the rest of the Quinebaug



#1 Lot number

o Well location

$\boxed{7}$ Yield in g.p.m.

(80') Depth of well

Figure 12.--Water yield from bedrock wells east of Pratt Read, Pla quadrangle (P-12N; 5.7-6.3W). Possible fault strike N. 75° and dips 50° NE. (Sketch and data provided b A. Randall.)

2480

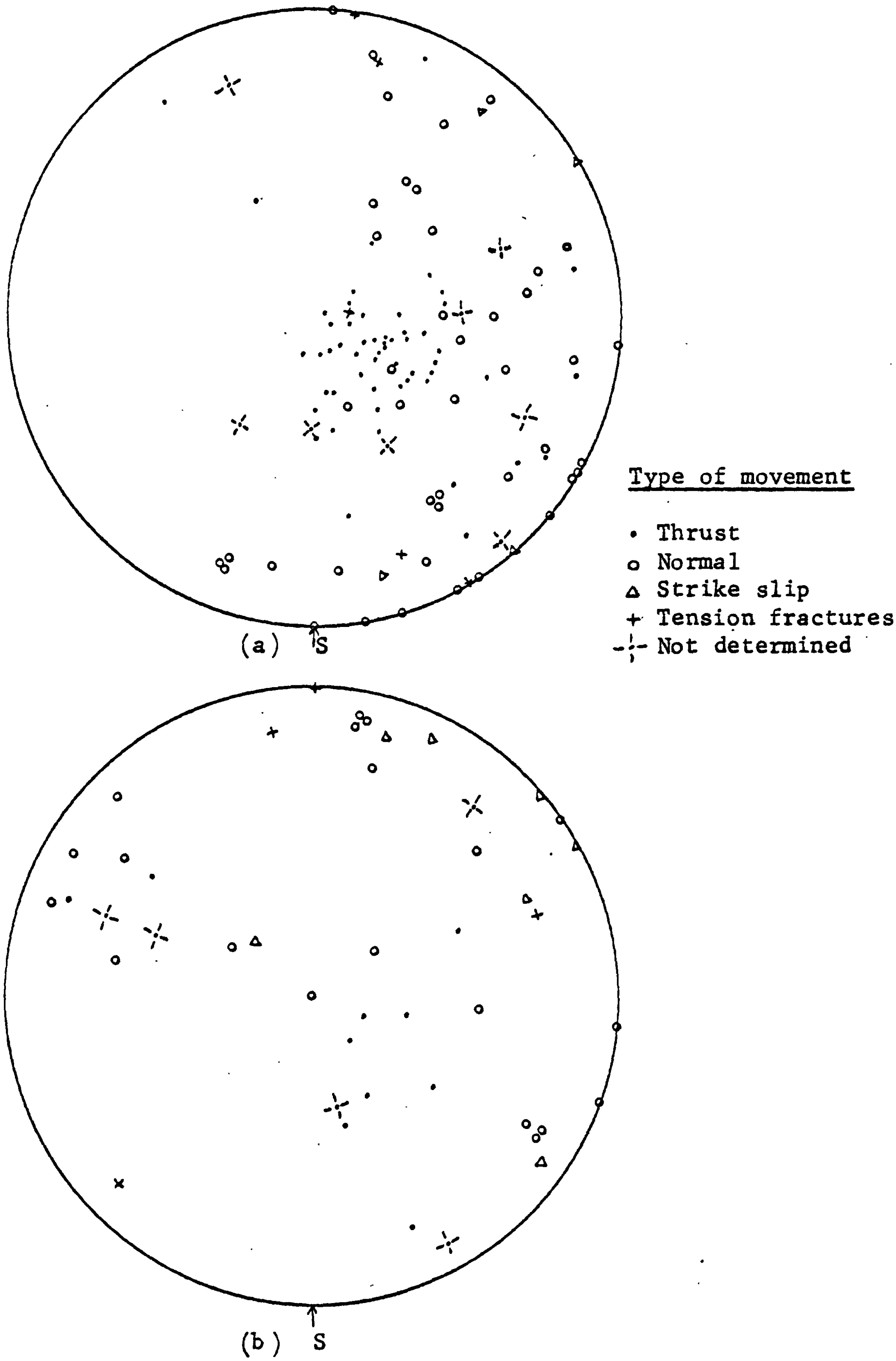


Figure 13.--Poles of the planes of minor faults in the Plainfield-Danielson area. Poles are plotted on the lower hemisphere of an equal area net.
(a) Faults in the Tatnic Hill Formation and upper member of the Quinebaug Formation.
(b) Faults in the Black Hill and lower members of the Quinebaug Formation.

Formation are in figure 13b. The greater number of points plotted in figure 13a is not an indication of a greater intensity of faulting in the Tatnic Hill Formation, but rather of a greater abundance of exposures in the Tatnic Hill than in the Quinebaug Formation. About half of the points plotted in figure 13b were measured in the cuts along the turnpike exit at Plainfield, and much of the rest of the Quinebaug Formation is probably equally strongly faulted.

The sense of movement of the observed faults is indicated on figure 13 where it could be determined. In most cases the movement was determined by drag along the fault plane. Almost half of the measured faults are low-angle thrust faults, and these are probably even more abundant than is indicated. They are commonly subparallel to the foliation and layering of the rocks, and thus are more difficult to see than are the high-angle faults. Cataclasis of many of the rocks suggests thrust faulting in places where an actual fault plane could not be seen. Slickensided surfaces can be observed on many of the faults, and also can be seen on fracture surfaces where no fault could be demonstrated. As a general rule slickensides are more common on high-angle faults than on low-angle ones, but they do occur on both. Crush zones also may be seen along some faults; in some cases this is fault gouge, but more commonly it is a rubbly zone a few inches to a foot thick.

FOLDS

Hampton Syncline.--The major fold in the Plainfield-Danielson area is the recumbent Hampton syncline, which is continuous to the southwest with the overturned Chester-Hunts Brook syncline. The trace of the axial surface of the syncline goes through the Scotland Schist and locally Hebron Formation in the northern part of the Hampton and Danielson quadrangles (pl. 3 and 2). Rocks south of the trace, including Scotland Schist, Hebron, Tatnic Hill and Quinebaug Formations and Canterbury Gneiss are in the normal limb of the syncline, and those north of the trace, including Scotland Schist, Hebron Formation, Brimfield Schist and Eastford Gneiss are in the overturned limb of the syncline. Evidence for the syncline in the Plainfield-Danielson area is not compelling, in part because of the scarcity of exposures in the area of the trace of the axial surface. The fold has been projected through the area primarily because of the correlation of the Brimfield Schist, which overlies Hebron Formation in the northwestern corner of the area, and the Tatnic Hill Formation which underlies Hebron in the eastern half of the area. Evidence for the correlation of the two units is southwest of the Plainfield-Danielson area, in the area of the Chester-Hunts Brook syncline (Lundgren, 1963, 1964, 1967; Goldsmith, 1961, 1967b and d).

The axial surface of the recumbent Hampton syncline has a generally shallow dip north and northwest. The surface is gently folded but there is no evidence in the Plainfield-Danielson area to indicate it is isoclinally folded; folding of the axial surface is probably related to doming of the Willimantic dome. The axis of the largest fold in the axial surface is about parallel to and west of the Natchaug River in the western part of the Hampton quadrangle. The general configuration of the axial surface across part of the Hampton quadrangle is shown diagrammatically in the block diagram of figure 14. The surface is within the Scotland Schist on the western and eastern sides of the Hampton quadrangle and in the Danielson quadrangle. In the center of the Hampton quadrangle Scotland is apparently squeezed out of the axial zone, except for the remnant pod southwest of Hampton Reservoir. There is, however, a lack of exposure in the zone of the axial trace, and it is possible there is a thin, continuous belt of Scotland on either side of the trace across that area. The block diagram suggests that the uppermost bed of Hebron Formation wraps around the synclinal hinge west of the Hampton quadrangle and is folded back on itself in the central part of the quadrangle where Scotland is squeezed out of the synclinal core. Thus the two layers of Hebron now in contact with each other across that area could be the same bed originally deposited several miles apart. It is, however, possible, if not probable, that there was some shearing of the rocks in the axial zone during overturning of the syncline, so that the Hebron layers on either side of the axial surface are not necessarily stratigraphically equivalent. Exposures of Hebron and Scotland in the southern part of the Putnam quadrangle are close to the trace of the axial surface, and the rocks are cataclastically deformed and cut by ultramylonite dikes, suggesting shearing in the axial zone in that area. No cataclastic rocks were observed in the Hampton quadrangle to suggest shearing in the axial zone, but small scale folds exposed in a railroad cut south of Hampton reservoir (H-26.0N; 16.4W) south of the projected trace of the axial surface, have been sheared off along planes subparallel to the axial surface (fig.15).

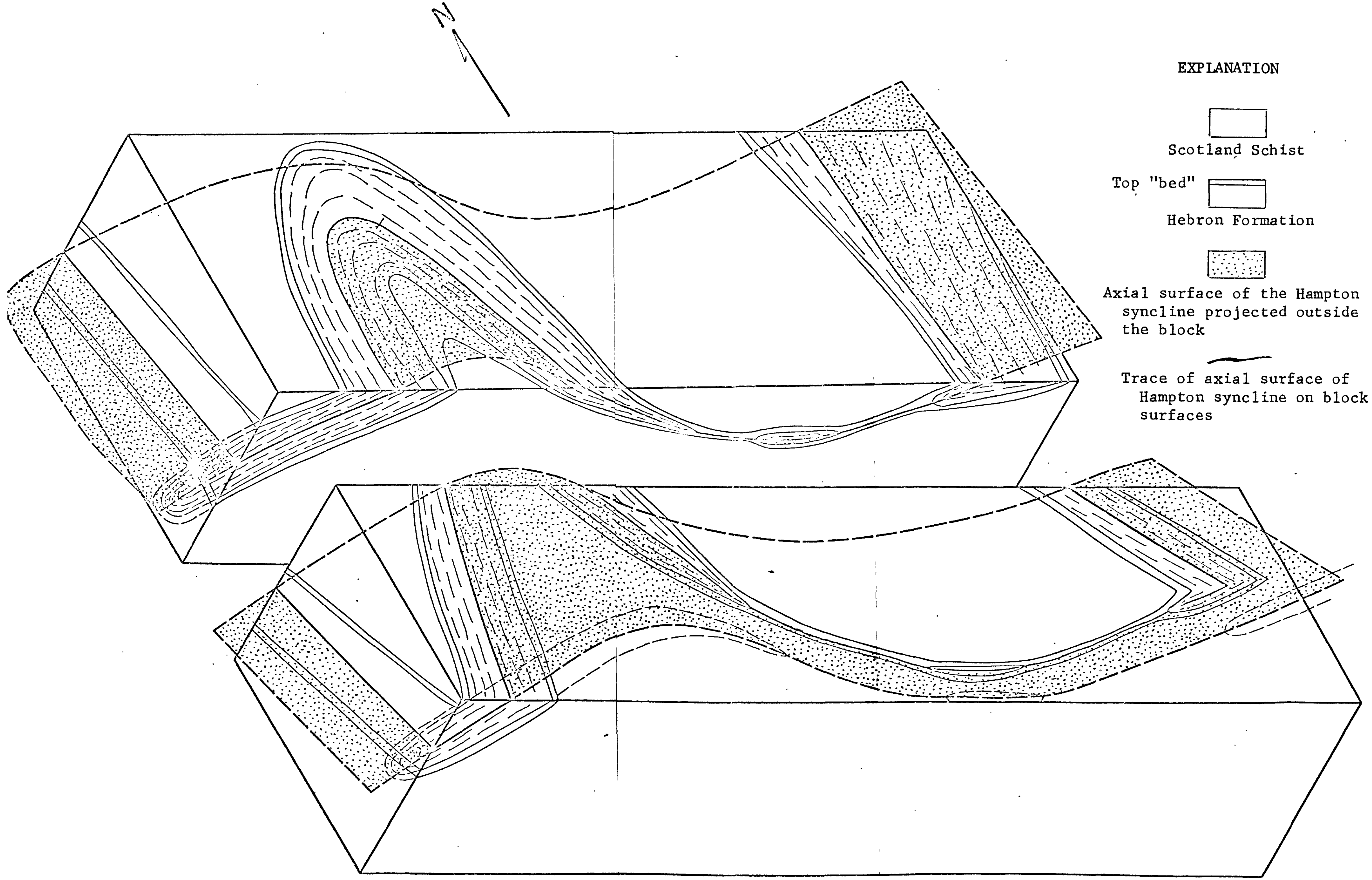
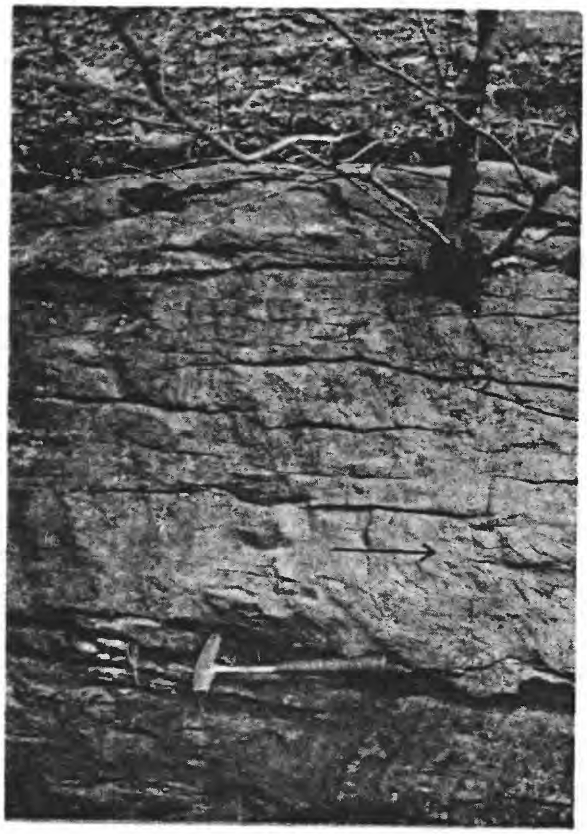


Figure 14.--Block diagram showing the axial surface of the Hampton syncline across central part of the Hampton quadrangle. Illustration is diagrammatic and not drawn to scale; approximate scale is 2 inches to a mile.

Figure 15.--Photographs of exposures of Scotland Schist and and of Hebron Formation in the Hampton quadrangle.

a - Exposure of Scotland Schist (H-29.5N; 14.2W), showing the hinge of the Hampton syncline. Arrow points in the bedding top direction (east) as indicated by graded beds. Axial plane cleavage strikes about parallel to the joint fractures and dips north (into the photo) about 12°.

b - Folded Hebron Formation exposed in cuts along the abandoned railroad south of Hampton Reservoir (H-26.0N; 16.4W). Exposure is below but close to the axial surface of the Hampton syncline. End of the hammer rests on a shear plane which has offset the folds.



(a)

(b)

The axis of the Hampton syncline apparently plunges north or slightly east of north at a low angle. The only exposed hinge of the fold is in an outcrop of Scotland Schist east of Catden Swamp (H-29.5N; 14.2W). In the outcrop well preserved bedding is essentially vertical, although slightly folded, and the cleavage, which is probably an axial plane cleavage, dips northwest about 15° (fig. 15a). Graded bedding, in which quartz and feldspar rich layers grade into micaceous layers, indicates bedding tops are to the east, which is consistent with the interpretation that the Scotland here is on the hinge of a syncline overturned to the east. The axial plunge measured in the outcrop is north 12°. The sharp discordance between well preserved bedding and axial plane cleavage in this exposure is considered to be an indication that the hinge is on a large fold. Small scale folds observed in outcrop in the area do not commonly have an axial plane cleavage, but the foliation follows the layering around the fold hinge, and primary bedding features are masked in the hinge as they are on the limbs. The gently dipping axial plane cleavage here is about parallel to the axial planes of small folds in the Hebron Formation of the railroad cuts (H-26.0N; 16.4W) just south of the projected trace of the axial surface (fig. 15b).

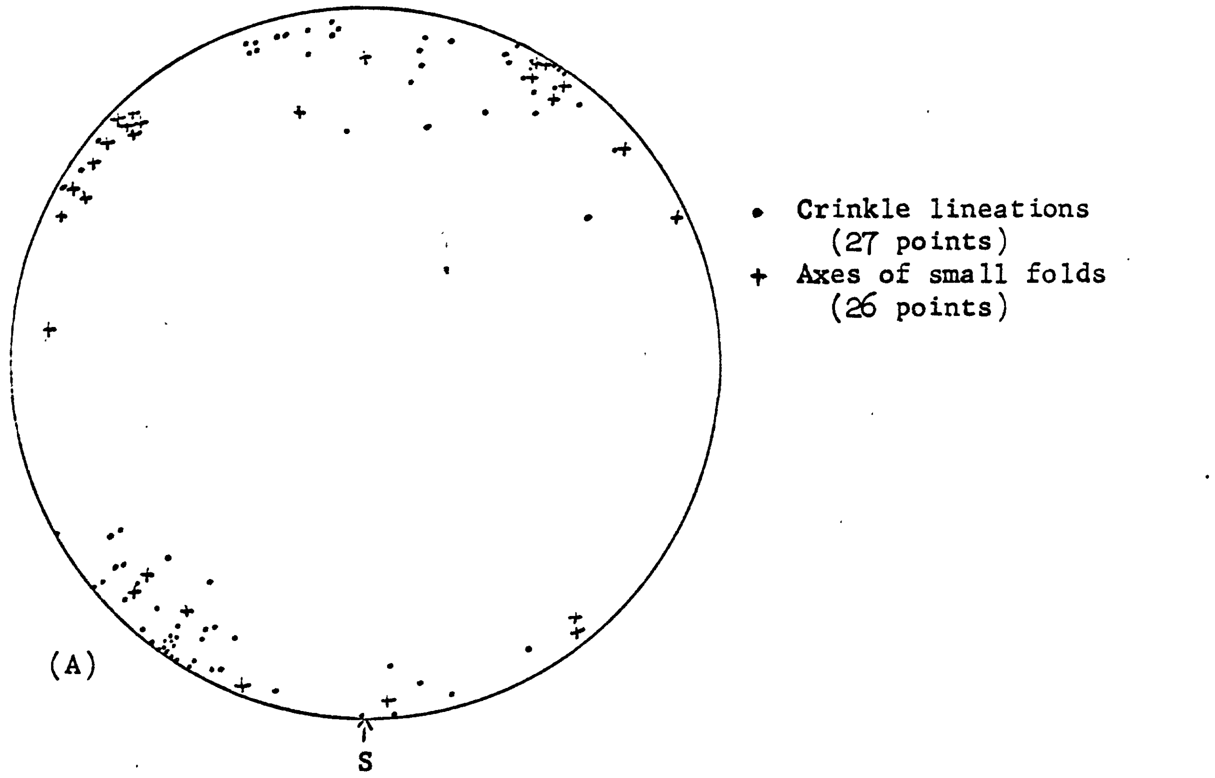
The change in lithology in the Hebron Formation on either side of the trace of the axial surface described earlier takes place quite abruptly and suggests a sedimentary facies change takes place west of the Plainfield-Danielson area. The Hebron in the central part of the Hampton quadrangle, south of the axial trace is typical well-bedded calc-silicate schist. Just north of the trace, on the hill slopes west of Hampton Reservoir and Catden Swamp, and in the belt of Hebron west of the Eastford Gneiss, the rock is predominantly less well-layered biotite-quartz schist. The change is most noticeable in the exposures in and south of the railroad cut (H-26.0N; 16.4W), and those on the hill slope to the north (see pl. 3). There is, on the other hand, some suggestion of a repetition of lithologies on opposite sides of the axial trace. The lenses of rusty weathering muscovite schist near the upper part of the Hebron are exposed in both the normal and the overturned limb.

Other folds.--A number of smaller folds are present in the Plainfield-Danielson area and reflect different stages of deformations. The first stage of folding probably accompanied the first stage of formation of the major folds of the area. A second fold stage took place in response to the west to east movement of the Hampton syncline, and probably the early stages of movement on the thrust faults. The third and youngest stage of folding probably accompanied upwarping of the Willimantic dome. The larger folds of the area, which are mapped out mostly in the Tatnic Hill Formation most likely relate to the first stage of folding. Small scale isoclinal folds observed in outcrops throughout the area reflect both the first and second fold stages, and it has not been possible to separate them in many cases. The third stage is reflected by both small and large open folds with steep axial planes.

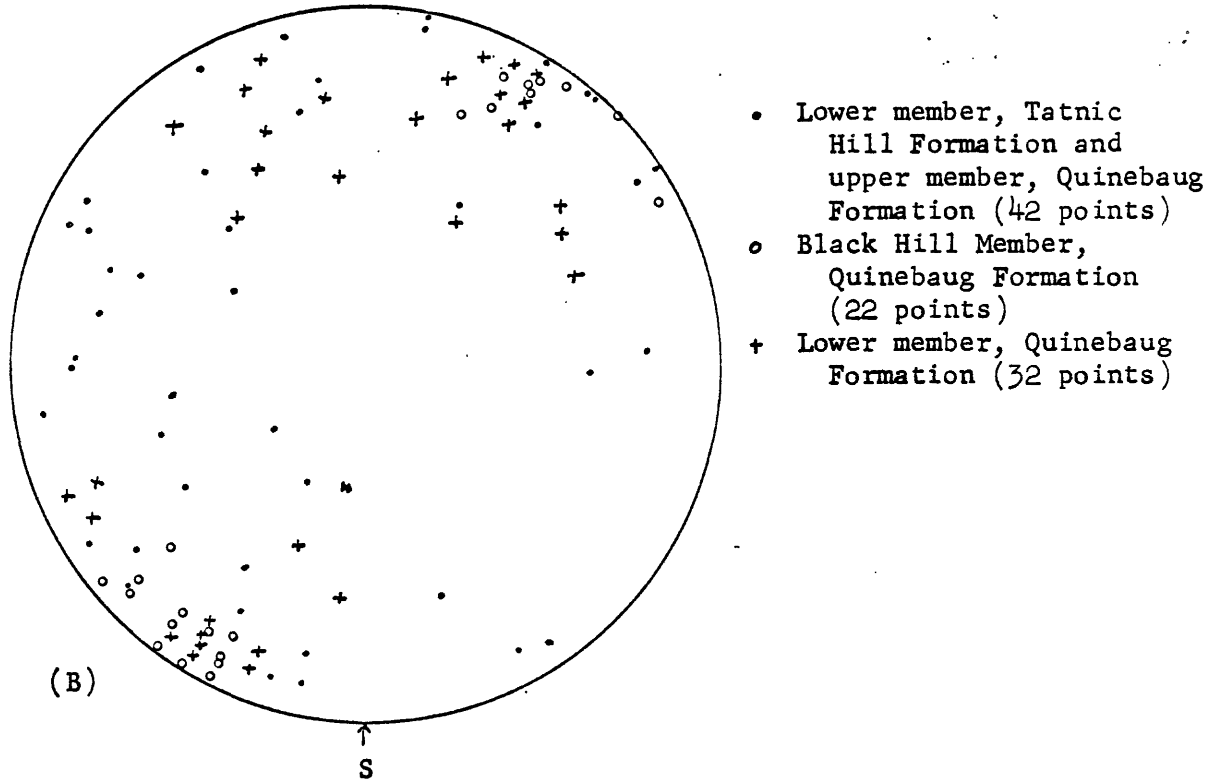
Probably most of the folds shown in the Tatnic Hill Formation on the Scotland, Plainfield and Danielson maps (pl. 5, 4, and 2) formed during the first stage of folding. Those folds involving the lower member of the unit are truncated by thrust faults and appear to have formed earlier than the cataclasis of the rocks. The large fold in the south-eastern corner of the Scotland quadrangle (pl. 5) could, however, relate to either the first or second stage. The axial plane of the fold has been warped, but is not isoclinally folded and the warping probably accompanied the youngest fold stage. Because of the rather prevasive overprint of foliation, lineation and folding during the second stage, the first stage of folding is difficult to recognize, and its axial directions are not yet resolved.

Small scale folds in the area apparently reflect both the first and second stage of folding. The axial plunge of the second stage is commonly gently north-northeast or south-southwest, but no consistent pattern has been worked out for the first stage folds. The majority of the small folds in the Scotland Schist, Hebron Formation and Yantic Member of the Tatnic Hill Formation, including the crinkle lineations in the mica rich rocks, reflect the second stage of folding (fig. 16a). The crinkle lineations in the micaceous rocks are the axes of minor folds. The group of northwest plunging fold axes in figure 16a are small folds in the Hebron Formation and may reflect the first fold stage, although the significance of these folds is not yet understood. The axial attitudes of the majority of the small folds in the Scotland and Hebron, and along the contact between them are subparallel to the axial attitudes of the recumbent Hampton syncline, and probably formed during the overturning of the syncline. Fold axes in the older rocks of the area show considerably more scatter (fig. 16b) and the folds probably represent both the first and second stage of folding. Some of the points plotted in figure 16b could be late drag folds along fault planes. Folds that could be identified in the field as drag folds were not plotted in the diagram, but many outcrops of the Tatnic Hill and Quinebaug Formations are probably bounded by faults, and some folds may be the result of drag on a fault which cannot be seen. A common feature in outcrops of the lower member of the Tatnic Hill is a change in dip of the foliation from shallow to about 60° at the edge of the outcrops. This could indicate either an early fold broken along a fault, or it could be drag along a fault, and in most exposures it is not possible to determine which. Some folds, on the other hand, have been sheared or broken by faults and are clearly earlier than the faulting. The folds in the older rocks with the most consistent axial directions are those in the Black Hill Member of the Quinebaug Formation (fig. 16b), and these probably all relate to the second stage of folding, as the axial planes dip west at a low angle and the axes plunge gently northward.

The third and apparently youngest fold stage is reflected in broad open folds with steep axial planes and shallow plunges. The largest of the late folds is the open syncline which covers most of the western half of the Plainfield-Danielson area and involves rocks of the Yantic Member of the Tatnic Hill Formation through the Scotland Schist (see structure section B'-B', pl. 3 and A'-A', pl. 5). The fold probably reflects upwarping of the Willimantic dome west of the Hampton and Scotland quadrangles (see Snyder, 1964b; pl. 1). The third fold stage is also observed as small open folds which deform all older foliations, lineations and some fault planes in outcrops throughout the area.



(A). Scotland Schist, Hebron Formation and Yantic Member of the Tatnic Hill Formation.



(B). Lower member of the Tatnic Hill Formation and Quinebaug Formation

Figure 16.--Plots of crinkle lineations and axes of small folds in the Plainfield-Danielson area; all plots are on the southern hemisphere of an equal area stereographic net.

Small scale structures

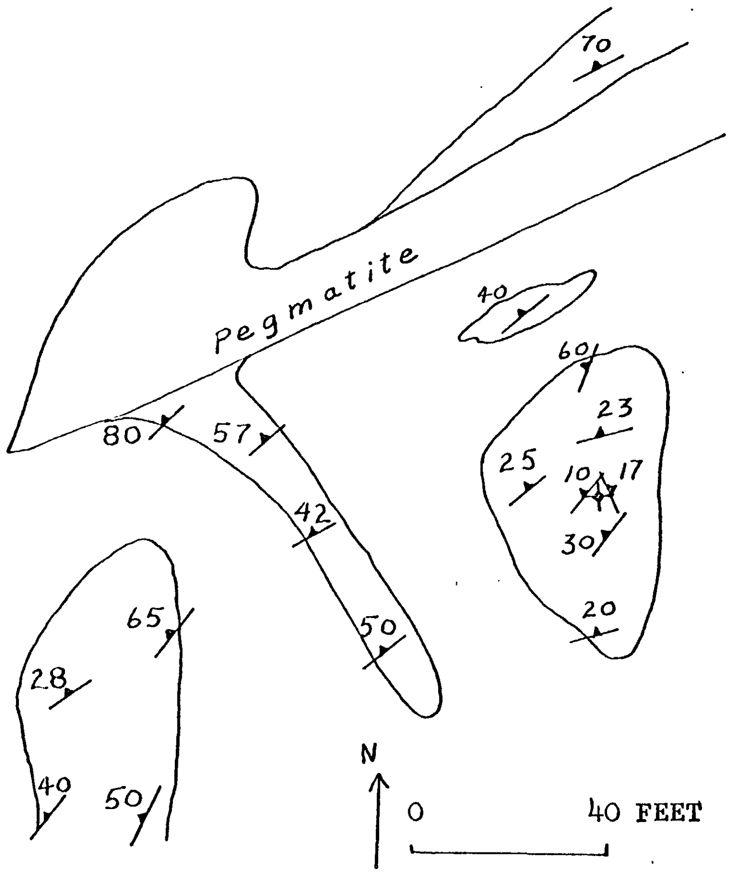
Attempts to analyse small scale structures, such as foliations, lineations, rotated minerals or pods (primarily of amphibolite), and boudins have been only partially successful. The structures do suggest three or possibly four fold stages and two fault stages. There is apparent overlap of the early stage of faulting (thrust faulting and cataclasis) with one or two stages of folding, and some of the small scale structures could reflect either folding or thrust faulting. In addition to several stages of small scale folding, discussed in the last section, repeated deformation is reflected in two foliation directions seen in many rocks, two or more lineation directions, and rotation of metamorphic minerals or foliated pods of rock. Interpretation of the structures, expecially in the lower member of the Tatnic Hill Formation and the Quinebaug Formation is complicated both by strong faulting which has disrupted the units and by obliteration of early structures by cataclasis. A detailed study of two localities, one in the Eastford Gneiss and the other in the Hebron Formation suggests that in selected areas between faults, detailed work might give some significant information on the various stages of deformation.

Foliation.--All rocks in the Plainfield-Danielson area are well foliated except a few, small, late pegmatites and the gabbro sill in the Plainfield quadrangle. The foliation is most commonly defined by a planar alignment and orientation of the minerals, which is commonly parallel to the compositional layering. In many rocks, and in particular the noncataclastic rocks, this is commonly a cleavage plane, but in other rocks it is not. Layering in many rocks is probably parallel to the original bedding; in some rocks, however, shear displacement can be demonstrated along the plane of layering, and in much of the area displacement has probably taken place along some layering planes even where it cannot be demonstrated. Thus, although the layering planes may be parallel to the original bedding, not all are true bedding planes. In the highly micaceous rocks, such as much of the Scotland Schist, the foliation is predominately a mica orientation, and layering is weak. In the unlayered gneissic rocks the foliation is also a mica schistosity, locally parallel to a weak lamination.

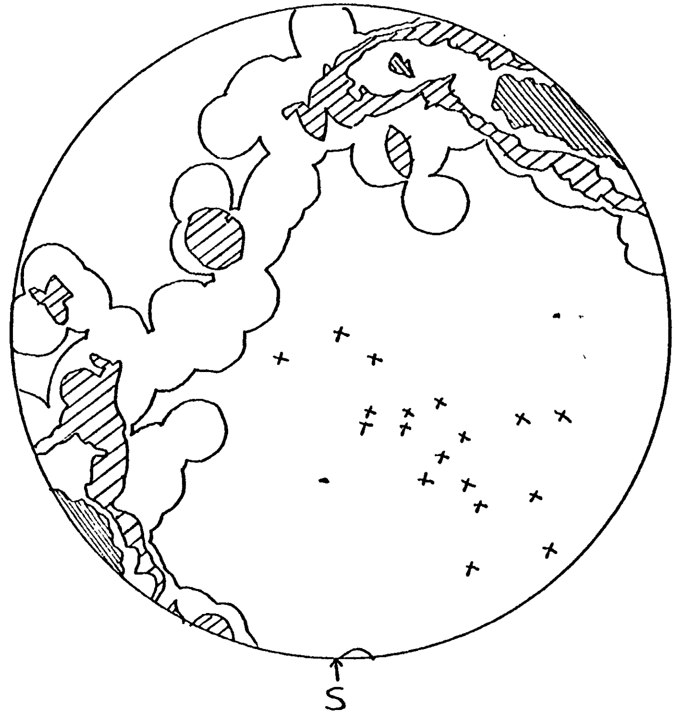
Two foliation planes are present in many rocks. In some of the mortar gneisses one plane is a cataclastic foliation superimposed on an earlier foliation. In others, however, streaks of granulation of mineral grains are parallel to both planes. Two foliation planes also occur in some noncataclastic rocks, such as the Eastford and Canterbury Gneisses, and in these both planes are defined by orientation and alignment of the micas. In only a few exposures is it possible to define a plane of layering (or bedding) at an angle to a plane of schistosity or cleavage.

A strong regional foliation which commonly strikes north-northeast and dips west at a moderate to low angle is the prominent foliation of the Plainfield-Danielson area. Locally, however, the foliation is deflected, as on the west side of the area, on the east flank of the Willimantic dome, where the foliation dips east at a low angle. Also in parts of the lower member of the Tatnic Hill Formation the attitude of the foliation is highly variable from outcrop to outcrop as well as within individual outcrops. It has not been possible to make a consistent structural pattern out of the varying attitudes, and they probably are folded foliations which have been subsequently faulted. The strong cataclastic foliation in the mylonites, mylonite gneisses and blastomylonites of the lower member of the Tatnic Hill Formation and the Quinebaug Formation is parallel to, and commonly defined by, the composition layering and lamination of the rocks. The cataclastic foliation commonly has a shallow west dip, although the dip is steep to vertical in a part of the lower member of the Quinebaug about 1,000 feet above the Lake Char fault. The steep dip may reflect a large drag fold on the fault plane in the rocks of the upper plate, but more likely the cataclastic rocks have been upturned along late faults.

The foliation planes, and the poles of the planes from several selected areas were plotted on a stereographic net to determine if the plane intersections were concentrated in a maximum. With two exceptions to be discussed later, no strong β maximum resulted from the plots, but the intersections tend to fall along a great circle, while the π poles concentrate around the pole of this great circle. This is, undoubtedly, a consequence of the strong regional foliation, which is fairly consistent within a given area; the great circle is, expectedly subparallel to the average attitude of the foliation planes. The strike of the great circle differs from one locality to the next, although in general it trends northeast and dips northwest. Only one example is given here for a small area in which the readings are more tightly controlled than in most places, and in which there was no particular indication of faulting between the areas of exposures. Figure 17a is a sketch map of outcrops of the sillimanite gneiss unit in the lower member of the Tatnic Hill Formation in the Danielson quadrangle (D-39.7N; 15.7W). The intersection of the foliation planes (fig. 17b) shows a stronger concentration than do most plots in the area, but the concentration is not strong, and is spread out along the great circle which represents the average strike of the measured foliation planes.



(a)



(b)

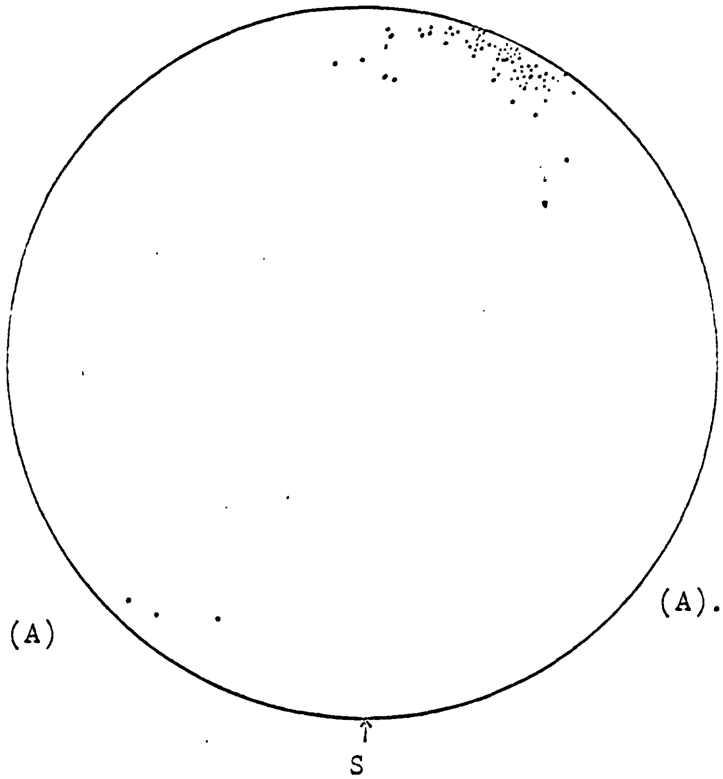
Figure 17.--Sketch map and β diagram of exposures of sillimanite gneiss in the lower member of the Tatnic Hill Formation, Danielson quadrangle (D-39.7N; 15.7W).
(a)- Sketch map, showing outcrops of sillimanite gneiss and pegmatite
(b)- β diagram; contour intervals 0.6, 2, 5, 10% per 1% area; 153 points
x, poles of the foliation planes

Lineations.--Lineations representing three or more stages of deformation have been recorded in the Plainfield-Danielson area, but have not been thoroughly sorted out. The youngest one is the cataclastic lineation in the mylonites and mylonite gneisses close to the Lake Char fault (see fig. 10). The next youngest, and in general the most common lineation in the area is north-northeast to north-northwest trending, with a shallow plunge. The lineation is formed by biotite streaks in the granitic gneisses, quartz rods in in the Hope Valley Alaskite Gneiss, some mineral lineations and S plane intersections, as well as some small fold axes and crinkles. Other mineral lineations and other small fold axes have other directions, and some at least are demonstrably older than the north-trending lineations as they are folded around north-plunging folds; probably they are all older.

Outside of the immediate zone of the Lake Char fault, the common regional lineation has a general 20° NW. to 20° NE. trend, and plunges north at a low angle, although it is locally reversed to south plunging. A few hundred feet away from the Lake Char fault both the cataclastic 70° NW. lineation and the regional lineation is visible in some rocks. The two lineations can be seen in rocks of both the upper and the lower plate of the fault, but are more common in the lower plate primarily because the granitic gneisses in the lower plate are more commonly lineated than the hornblende gneisses in the upper plate. Because of the gentle plunge of the regional lineation, the common north plunge could be reversed by only minor warping or by rotation of a fault block. The regional north-plunging lineation is thought to represent a "b" lineation for the west to east movement of the Hampton syncline and the thrust faults.

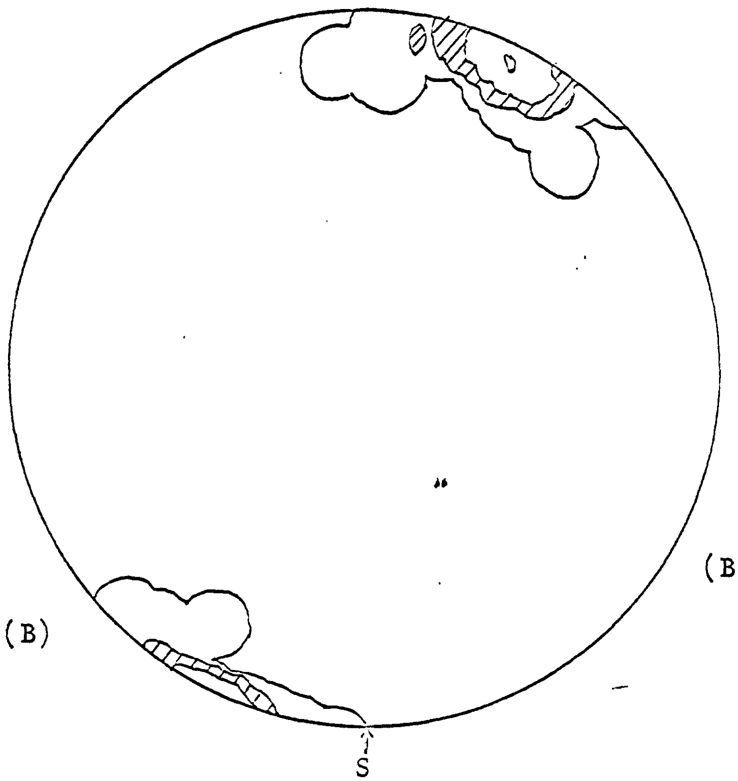
In the gneisses of the Sterling Plutonic Group the regional lineation is formed by biotite streaks in the Scituate Granite Gneiss and by quartz rods in the Hope Valley Alaskite Gneiss. The rodded quartz is one of the characteristic features of the Hope Valley (Moore, 1958). A gentle north plunge is typical of the lineations in the Scituate and Hope Valley in the adjacent quadrangles (Feininger, 1965b; G. Moore, 1966, personal communication).

In the rocks of the upper plate of the Lake Char fault the trend and plunge of the lineations are quite variable, especially in the Quinebaug Formation and the lower member of the Tatnic Hill Formation. The regional lineation is present in these rocks, but it is the prominent lineation only in the granitic gneisses of the Canterbury and Eastford Gneisses and in the younger metasedimentary rocks, primarily the Scotland Schist and Hebron Formation. The mineral lineations and S plane intersections of various units, or groups of units are plotted in figures 18, 19, and 20. The lineations plotted in figure 18 and 19 are defined by streaks of biotite flakes in the Eastford Gneiss (fig. 18) and the Canterbury Gneiss (fig. 19). In both units the lineation is apparently at the intersection of two foliation planes. The lineation trend in the Eastford Gneiss, in the overturned limb of the Hampton syncline, is strongly concentrated in the 20° NE. trend direction, while that in the Canterbury, in the normal limb of the syncline, is more variable, but is in general concentrated in the 20° NW. direction. The northeast trend of lineations in the overturned limb is also reflected in the lineations in the overturned Hebron plotted in figure 20a, but the lineations in the rocks of the normal limb generally range from the 20° NE. to the 20° NW. plunge direction. The mineral lineations in the Hebron in Day



(A)

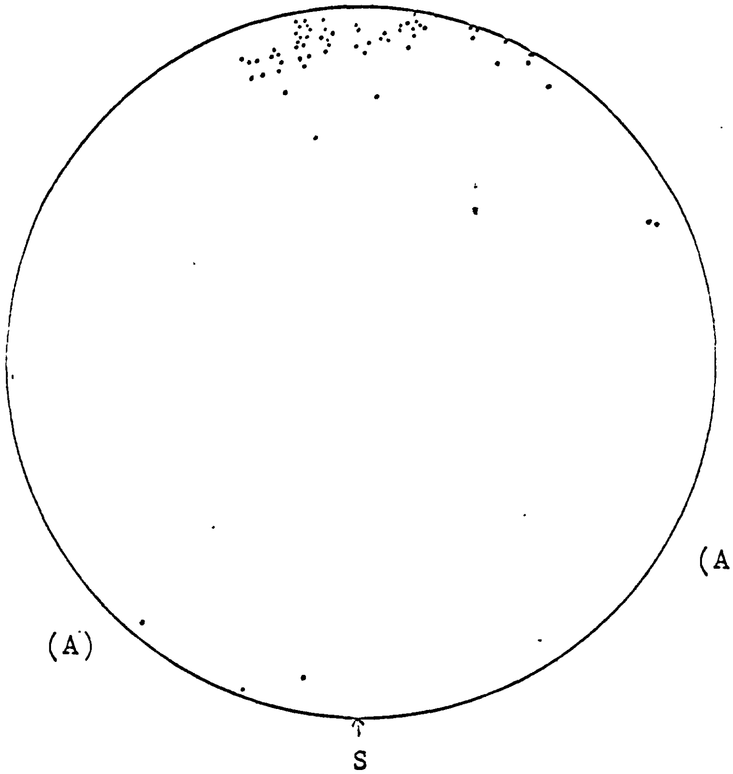
(A). Plot of lineations;
79 points



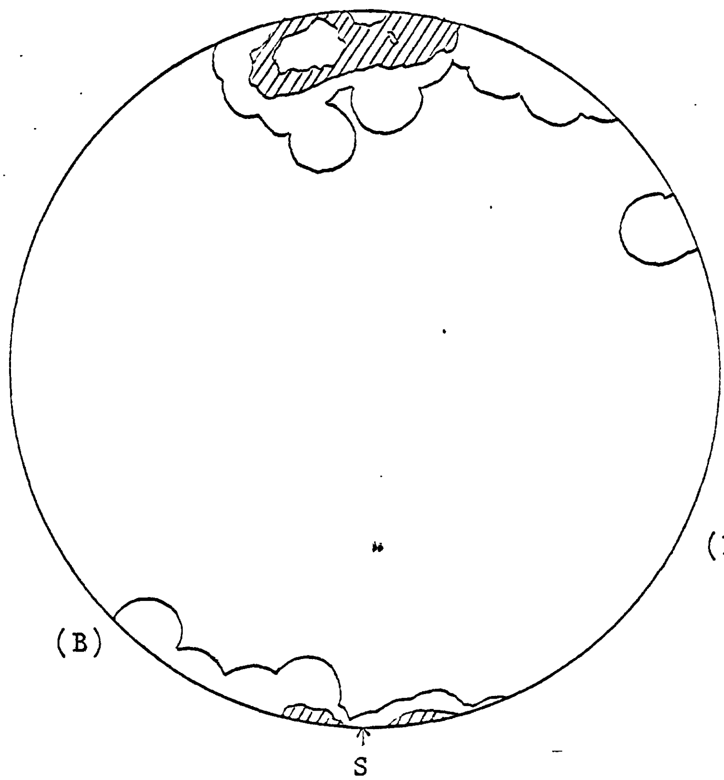
(B)

(B). Contour diagram;
Contour intervals;
1.3, 6, 19, 45% per 1% area

Figure 18.--Biotite lineations in the Eastford Gneiss; plots are on the southern hemisphere of an equal area stereographic net.



(A). Plot of lineations;
64 points



(B). Contour diagram;
Contour intervals,
1.5, 12.5, 25% per
1% area

Figure 19.--Biotite lineations in the Canterbury Gneiss; plots are on the southern hemisphere of an equal area stereographic net.

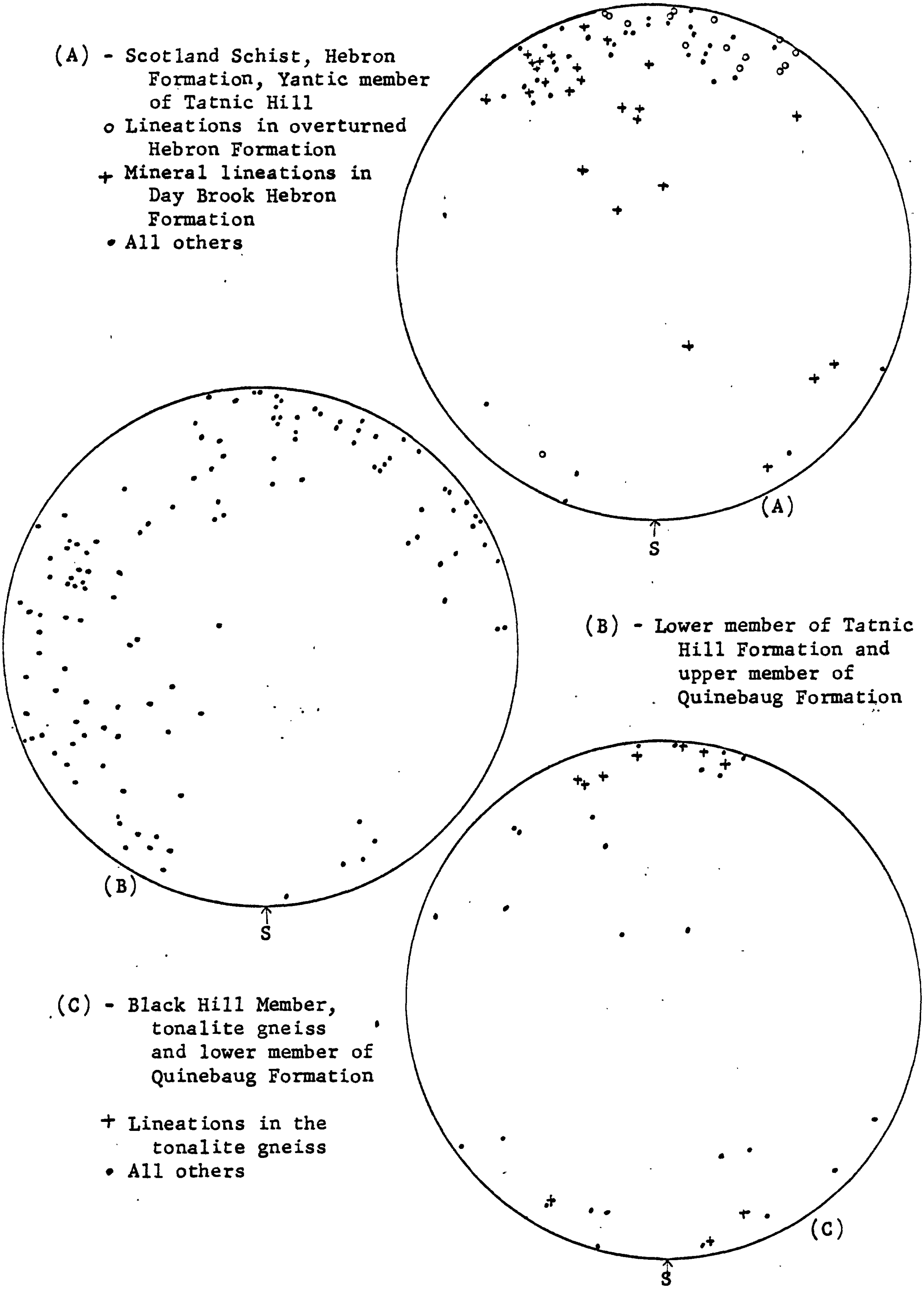


Figure 20.--Plot of mineral lineations and S plane intersections; plot on the southern hemisphere of an equal area sterographic net.

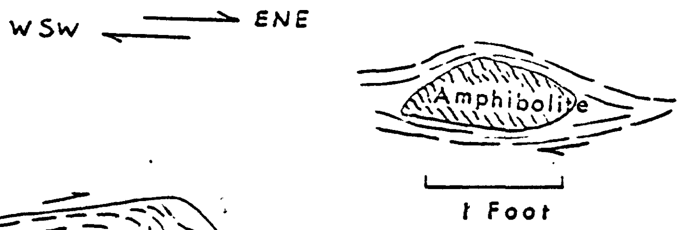
Brook (Danielson quadrangle) will be discussed more thoroughly later, but they apparently reflect an earlier lineation than the regional north-plunging one. The regional lineation is also reflected to some degree in the Tatnic Hill Formation (fig. 20b) and the Quinebaug Formation (fig. 20b and c), but the lineation in the tonalitic gneiss of the Quinebaug Formation (fig. 20c) is the only one in these units that consistently reflects the regional lineation.

The distinction between lineations produced by S plane intersections and mineral lineations was not made for many of the lineation measurements. Probably most, if not all, S plane intersections are parallel to the regional lineation, but many mineral lineations are earlier than the regional lineation, and it is not known whether they all are or not. The scatter in lineation directions show in figure 20b and is no doubt because of different ages of lineations. In the lower member of the Tatnic Hill Formation (fig. 20b) there is a fairly strong concentration of lineations around a 65° NW. to 65° NE. direction, which is commonly formed by alignment of clusters of sillimanite needles or of pods of sericite after sillimanite. The significance of the direction of lineation is not clear, but it is probably older than the regional lineation.

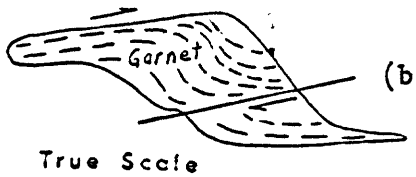
<u>Other features</u>.--Features such as boudinage, rotated minerals and rotated pods of rocks are fairly common only in the lower part of the lower member of the Tatnic Hill Formation and the upper part of the upper member of the Quinebaug Formation. Some such features are illustrated in figure 21, all of which were observed on the east side of Tatnic Hill in the Danielson quadrangle.

Rotated mineral grains are not common in the area. Some coarse feldspar grains in the mylonite and mylonite gneisses have been rotated, but in many rotation is not obvious. The rotated garnet sketched in figure 21a is the only garnet observed in the area, either megascopically or microscopically, which showed indications of rotation. Boudinage also is not common. Many pods of amphibolite, especially in the Quinebaug Formation, look on the two dimensional surface as though they may be completely separated boudins, but where they can be observed in three dimensions, most are essentially equidimensional blocks rather than elongated. Many of these blocks are banded amphibolite, and have been rotated so that the banding is at an angle to the layering and foliation of the surrounding gneiss (fig. 21b). The rotation is consistently clockwise, indicating the upper part moved eastward relative to the lower part. In one outcrop an amphibolite layer has been boudinaged, and the boudins subsequently stacked up on each other (fig. 21c) from west to east. Small drag folds may occur in the gneiss surrounding some amphibolite pods or pegmatites (fig. 21d), and these again indicate an eastward sense of movement of the upper part.

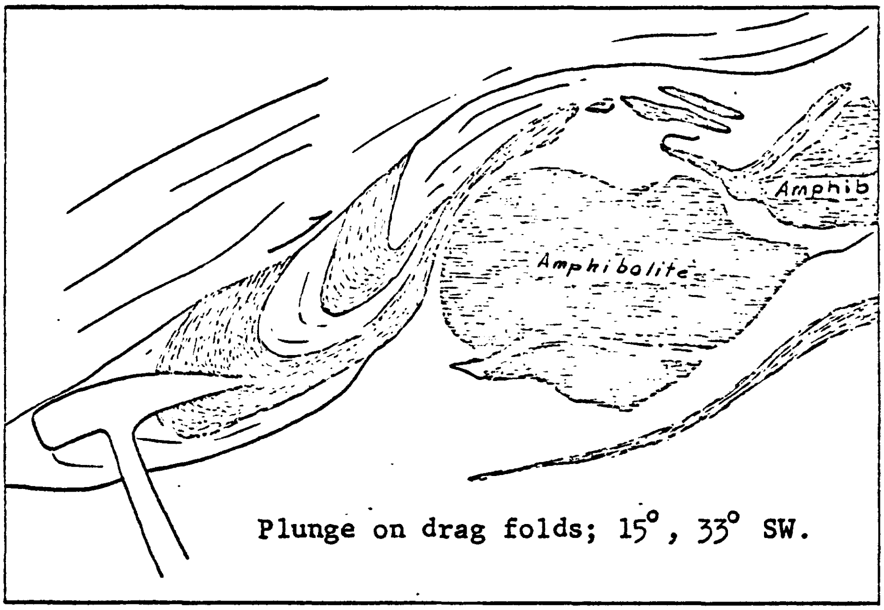
All of these features observed in the Tatnic Hill and Quinebaug Formations indicate a consistent movement sense of the upper layers moved east to northeast relative to the lower layers. The movement pattern is consistent with the structural position of the rocks on the east flank of the Hampton syncline. The sense of movement is also consistent with movement of the regional thrust system and the west to east movement of the Hampton syncline, both of which are later than the original fold system. Most of the features are associated with cataclastic rocks, and appear to have formed late in the tectonic development of the rocks. Thus the movement indicated is probably late and reflects the west to east movement of the thrust faults.



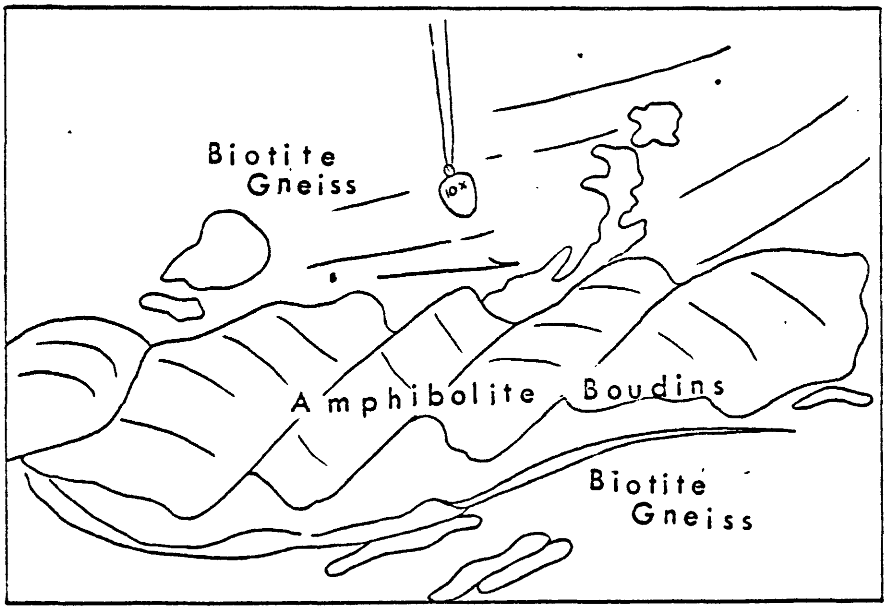
(b). Rotated amphibolite pod



(a). Rotated garnet; looking south on N. 75° W., 90° joint



(c). Small drag folds along a shear plane (scale is indicated by hammer).



(d). Stacked up amphibolite boudins (scale is indicated by the hand lens).

Figure 21.--Sketches of small scale features indicating west to east movement in the lower member of the Tatnic Hill Formation. Features were observed on the west side of Tatnic Hill, Danielson quadrangle.

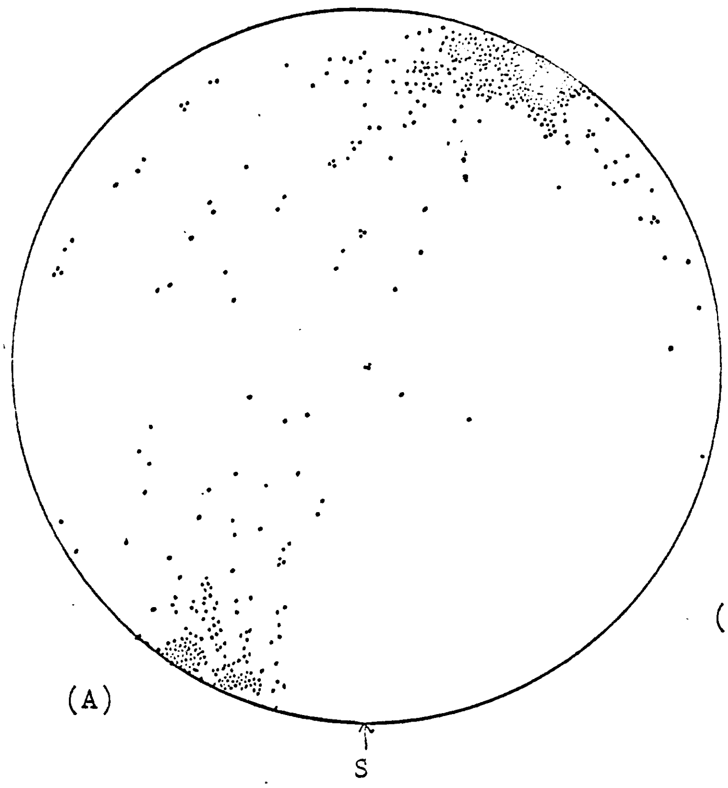
Specific localities

Eastford Gneiss.--An almost continuous exposure of Eastford Gneiss about a mile long and 50 feet wide is provided in the Hampton quadrangle along a buried gas line where the bedrock was scraped bare of the thin mantle of overlying till (H-33.5N; 15.7W to 31.7N; 20.2W). The gas line trends almost at right angles to the strike of the prominent foliation of the gneiss, and provides a rare opportunity of an almost complete section across the gneiss. The exposure was, therefore, measured; the most common features of the gneiss which were measured included the prominent biotite lineation, one, and where possible two foliation planes, and the trend and direction of offset of the small shear planes in the gneiss. The two foliations in the Eastford are both primarily planes of alignment and orientation of biotite flakes, and in some rocks both are well defined and readily seen, while in others one or both are obscure and difficult to see; this is especially true of gneiss which contains only a few percent of biotite, as does much of the Eastford in the gas line. For this reason many of the foliation readings were viewed with some skepticism at first.

After the measurements were completed the foliation readings were tabulated and divided into two groups. One group included those readings that are essentially parallel to the regional foliation of the area, and that average about N. 15° - 25° E. and dip 15° - 25° NW; this group is designated S_2. The second group included the readings which diverge from the average, and are designated S_1. Where two directions were measured one is always close to the average, and the other varies from horizontal to vertical. Where only one plane could be observed, it was most commonly the S_2 direction. The S_1 measurements were plotted on a sterographic net in the manner of bedding planes, and the intersections of the planes obtained and contoured. The results, shown in figure 22a and b, rather surprisingly gave the strongest β maximum which has been obtained in the Plainfield-Danielson area. The lineations and the poles of all measured S planes are plotted in figure 22c, and the lineations and poles of S_1 planes only are contoured in figure 22d. A summary of the contoured data is shown in figure 22e. The β maximum of the S_1 intersections is close enough to the B maximum of the lineations as to be considered coincident, and both maxima are the pole of the π plane defined by the poles of the S_1 planes. This coincidence is too strong to be accidental, and the two foliations are considered to be real.

In the Eastford Gneiss the S_1 foliation apparently represents an early foliation which was deformed by a subsequent deformation when the regional or S_2 foliation was formed. The S_1 may be an igneous foliation, but because of the similarity in appearance between the two foliations, it seems more likely that both are metamorphic foliations, and the S_1 was induced during an early stage of deformation and metamorphism. The strong lineation at the intersection of the two foliation planes is apparently a "b" lineation for the second deformation. The early deformation may have accompanied the folding and metamorphism during the initial stages of folding of the Hampton syncline. The second deformation would then have accompanied the refolding and eastward movement of the Hampton syncline.

The shear planes in the Eastford Gneiss, which can be designated S_3, apparently represent a still later deformation, of more limited effect. A rose diagram showing the directional trend and offset of the small shears measured along the gas line is shown in figure 23. Most



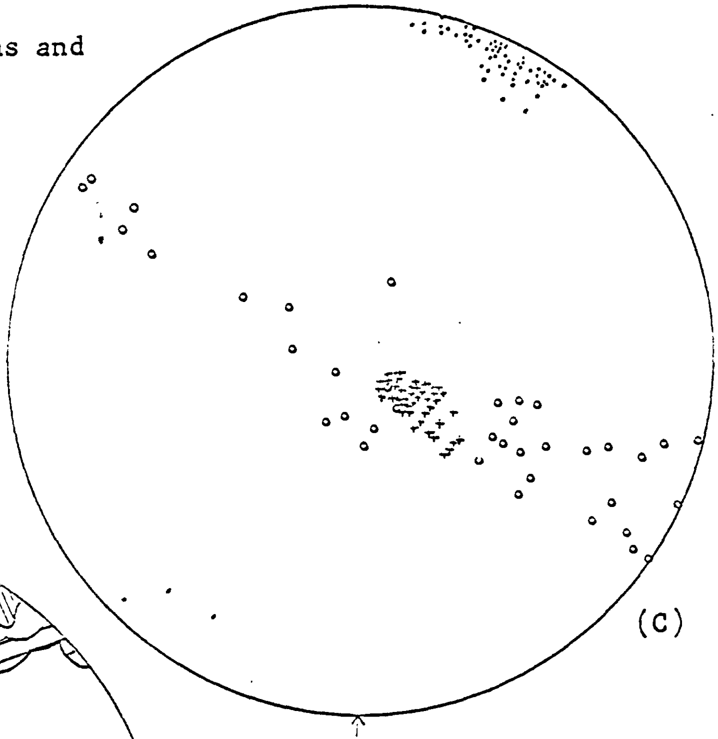
(A). β intersections of 35 S_1 planes; 595 points

(B). Contour diagram of β intersections; contour intervals, 0.5, 1, 10, 20, 33% per 1% area.

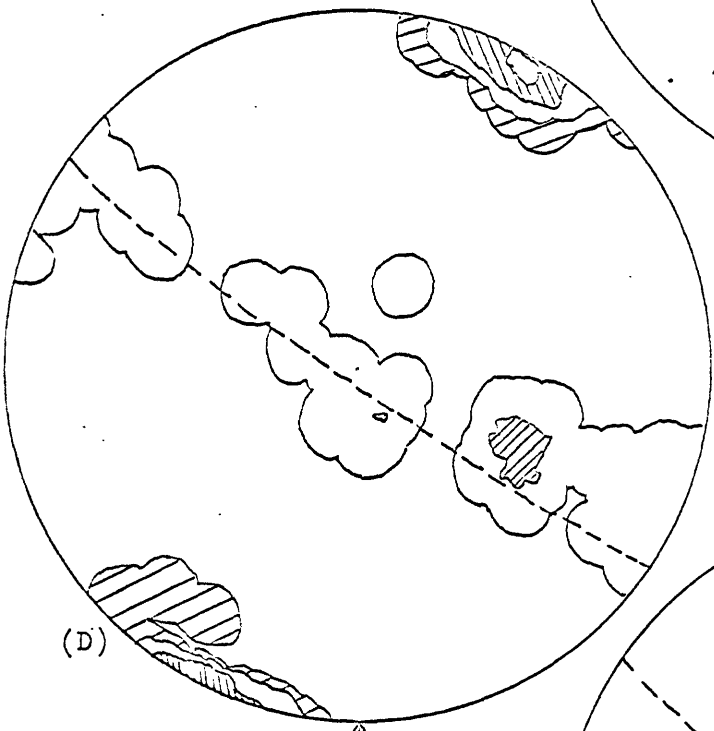
Figure 22.--Stereographic plots of foliation planes and lineations in the gas line exposure of Eastford Gneiss, Hampton quadrangle; all plots are on the southern hemisphere of an equal area stereographic net.

(C). Plot of biotite lineations and poles of S planes

- • Lineations (59 points)
- o Poles of S_1 foliations (38 points)
- + Poles of S_2 foliations (42 points)



(D). Contour diagram of lineations and poles of S_1 foliations
Contour intervals:
Lineations; 1.7, 8, 25, 50% per 1% area
S_1 poles; 2.6, .3% per 1% area



(E). Summary diagram

β maxima = 5°, 33° NE.
B maxima = 5°, 28° NE.

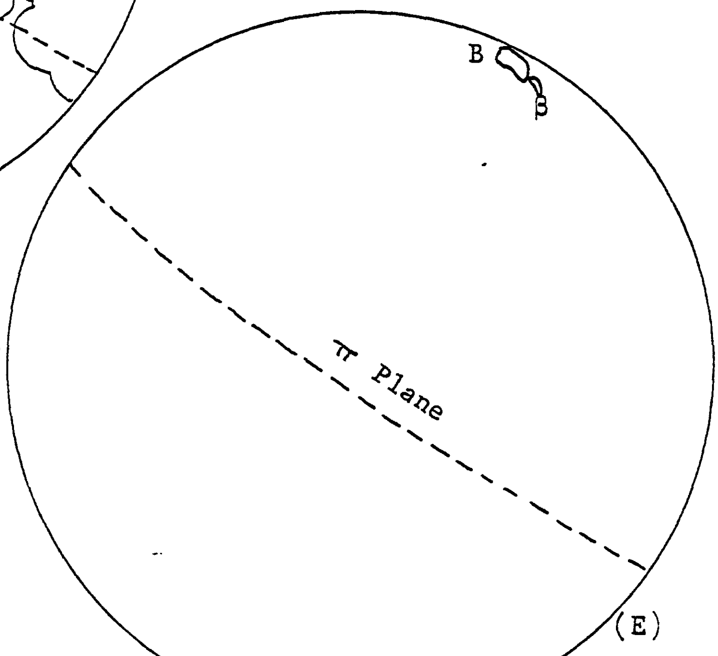


Figure 22.--Stereographic plots of the gas line exposure of Eastford Gneiss, Hampton quadrangle, (continued).

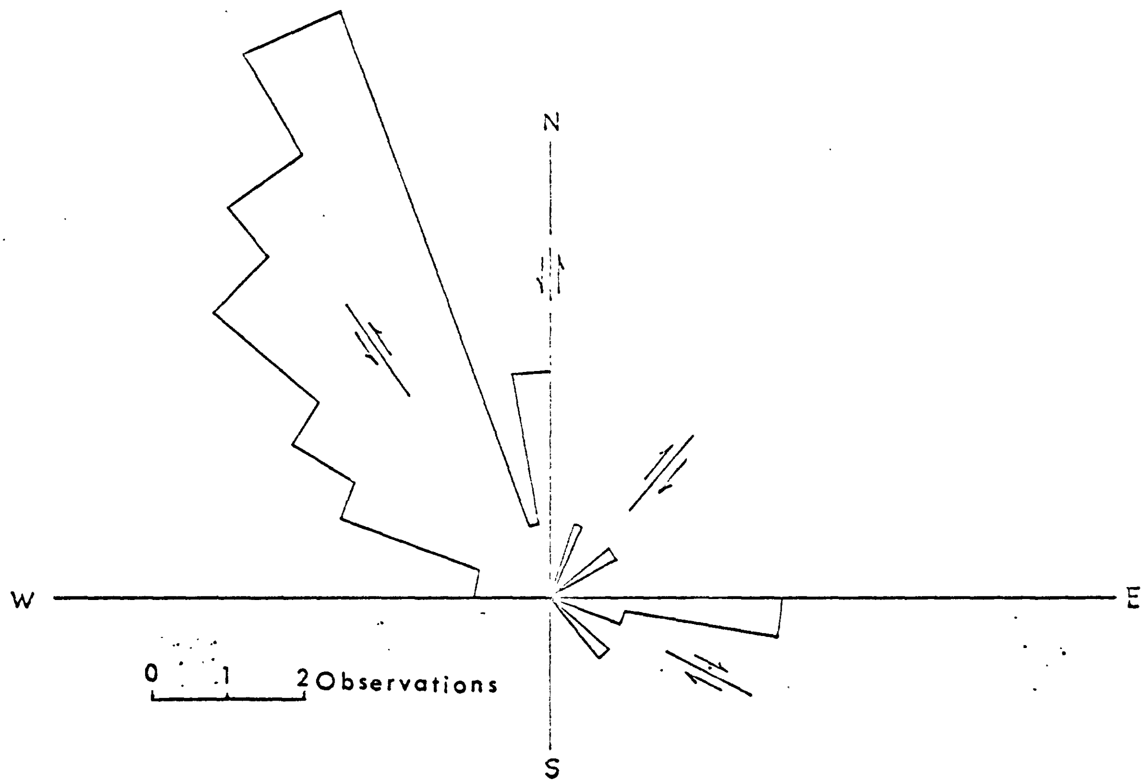


Figure 23.--Rose diagram showing the trend of shear planes in the gas line exposure of the Eastford Gneiss, Hampton quadrangle. Arrows indicate the movement sense on the shear planes.

of the shear planes trend N. 35° - 50° W. and have a right lateral sense of movement on the horizontal surface. The strike and dip of the shear planes could not be measured along the gas line, as all were observed on a two dimensional surface only. Similar shear planes in the road cuts along Route 44 strike about N. 45° W. and dip 45° - 60° NW. The shear planes offset both foliation planes, aplites and many cross-cutting pegmatites; some have a thin (about 1/4 inch) filling of pegmatitic or granitic material along the shear plane and still others are cut by late pegmatites. Offset is less than a foot on all shear planes, and commonly there is no actual discontinuity, but an S shaped swerve along the shear plane. The shear planes are obviously late structures, and possibly formed in response to the release of pressures in the area after the final stage of movement.

Day Brook.--In the northern part of the Danielson quadrangle, Day Brook flows over almost continuous bedrock for about a quarter of a mile (D-44.0 - 44.8N; 20.4W). The rock in the stream is Hebron Formation. At the southern end of the exposure, Scotland Schist occurs in both banks and about 100 feet south of the bedrock exposures there is an indication that Scotland underlies the stream bed. A sketch map of the stream and the area of exposure is shown in figure 24. The Scotland in the west bank overlies the Hebron in the stream, and that on the east bank is overlain by Hebron, suggesting a small isoclinal anticline in the stream. Two faults are exposed in the stream, dividing the exposure into three segments. Scotland Schist was not observed north of the southernmost fault, but lenses of muscovitic schist occur interlayered with the Hebron in the northern two-thirds of the stream. In the central part of the exposures, between the two faults, attitudes near the center of the stream

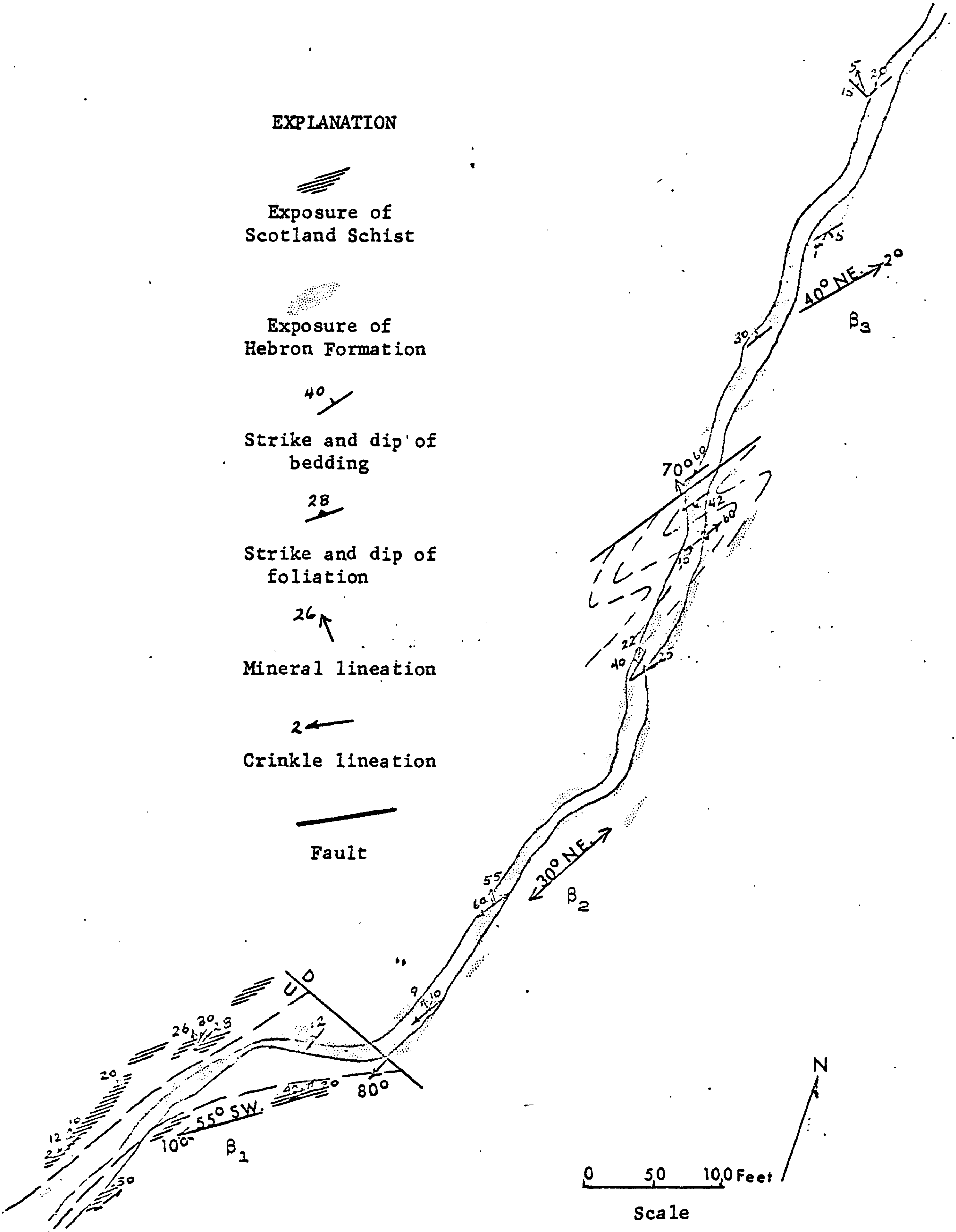


Figure 24.--Sketch map of Day Brook, Danielson quadrangle (D-44.0-44.8N; 20.4W).

suggest a fold axis is about in the middle of the stream, trending parallel to the stream.

Much of the Hebron exposed in Day Brook contains two S planes; one is a plane of compositional layering and is probably a bedding plane, and the second S plane is a cleavage, which locally appears to be a slip cleavage. Some of the Hebron is massive and poorly layered and both S surfaces are obscure; the most prominent planes in these areas are joints which break the rock into parallelogram shaped blocks. Two lineations can also be observed in much of the Hebron. One is a mineral lineation which is variable in plunge, and is deformed by and older than a crinkle lineation. The latter is apparent in the mica rich rocks, which are more abundant in this area than is common in the Hebron elsewhere.

The foliations and lineations measured in Day Brook were plotted on a stereographic net and the results are shown in figures 25 and 26. The β intersections of the planes of compositional layering, or the probable bedding planes, are shown in figure 25, with a separate plot for each of the three segments of the exposure. Each of the three plots show a fairly strong β maximum which is generally close to the B maxima defined by the crinkle lineations. The weakest of the three plots is the southern one (fig. 25a), in which there is a tendency for the intersections to be strung out along a great circle and the contoured β maximum is northwest of the crinkle lineations. The orientation of the β maximum is different in each of the three plots, suggesting that they have been shifted by the faults. The differences may not be real, but may be due to observational error; the differences are not large, especially between β_2 and β_3. A composite β diagram has not been attempted, but the plot of

S poles in figure 26a and b suggests a β maximum would be about horizontal, trending 40° NE. A plot of the crinkle and mineral lineations is given in figure 26c, and the crinkle lineations are contoured in figure 26d. The directional difference of the β maxima in the three segments of the exposure does not appear to be reflected in the crinkle lineations, but the B maximum defined by the crinkles is closely coincident to β_2, β_3 and to the pole of the π planes defined by the S poles (see fig. 26e).

There is a suggestion in figure 25 and 26c that the mineral lineations may be aligned along the π plane. The fit is not good enough to be certain, however, and further checking is needed. The mineral lineations are on the bedding planes rather than cleavage planes, where the two are not parallel, and are commonly deformed by and older than the crinkle lineations.

The information gained from the Day Brook exposure is generally similar to that gained from the gas line exposure of Eastford Gneiss. An early deformation is reflected in the mineral lineations. The B maximum defined by the crinkle lineations, which is about coincident with the β maxima, is probably a "b" lineation for a later deformation, which resulted in the prominent cleavage. Small folds observed in the exposures, and probably also the larger ones in the stream, but not directly observed, were apparently formed during the late deformation as their axial directions parallel the regional foliation and the β and B maxima. The directional elements of the late deformation suggest it was contemporaneous with the second deformation that produced the regional foliation (or S_2) and strong lineation in the Eastford Gneiss.

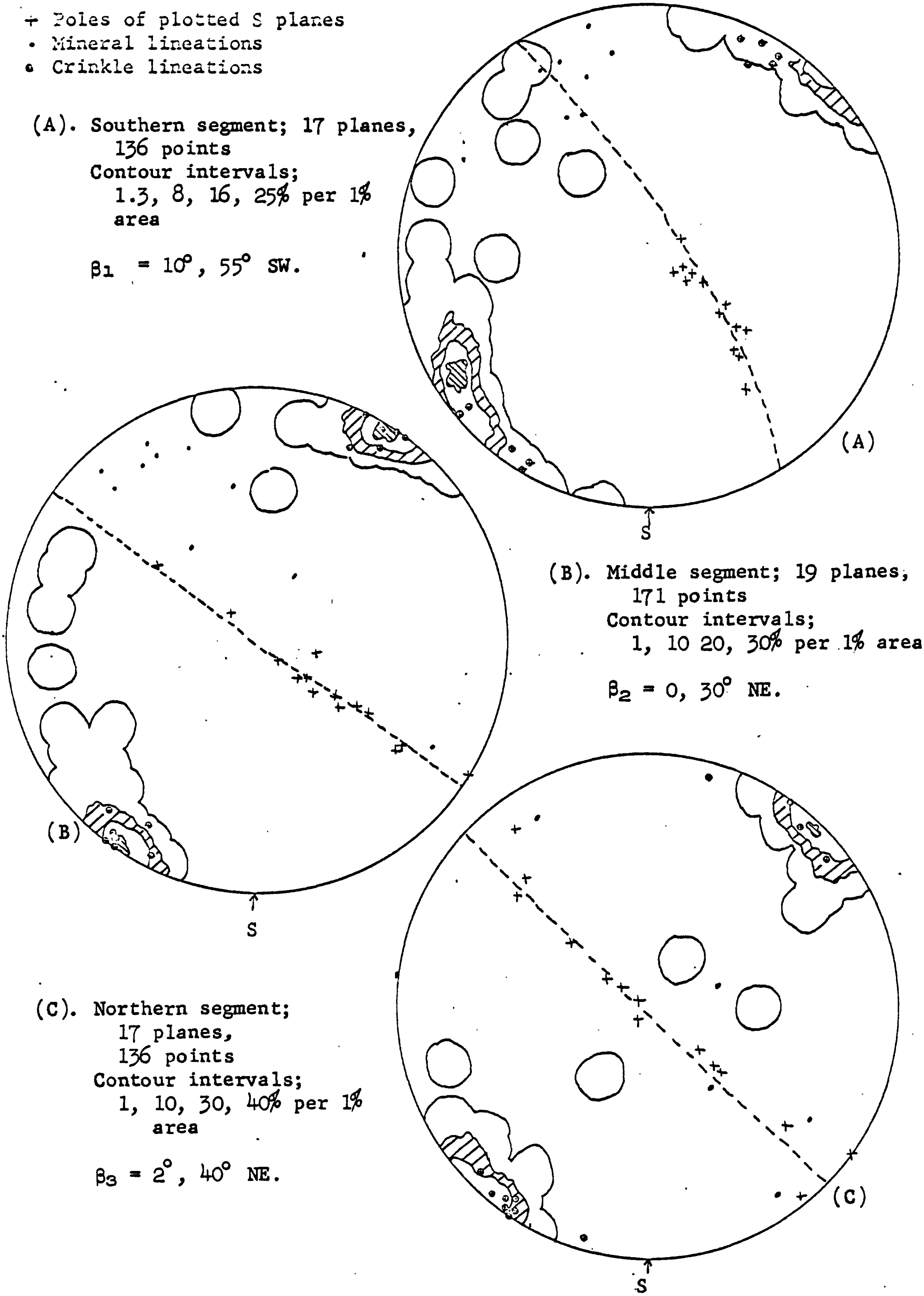


Figure 25.--β and π diagrams of bedding plane foliations in the Hebron Formation in Day Brook, Danielson quadrangle (D-44.0-44.8N; 20.4W).

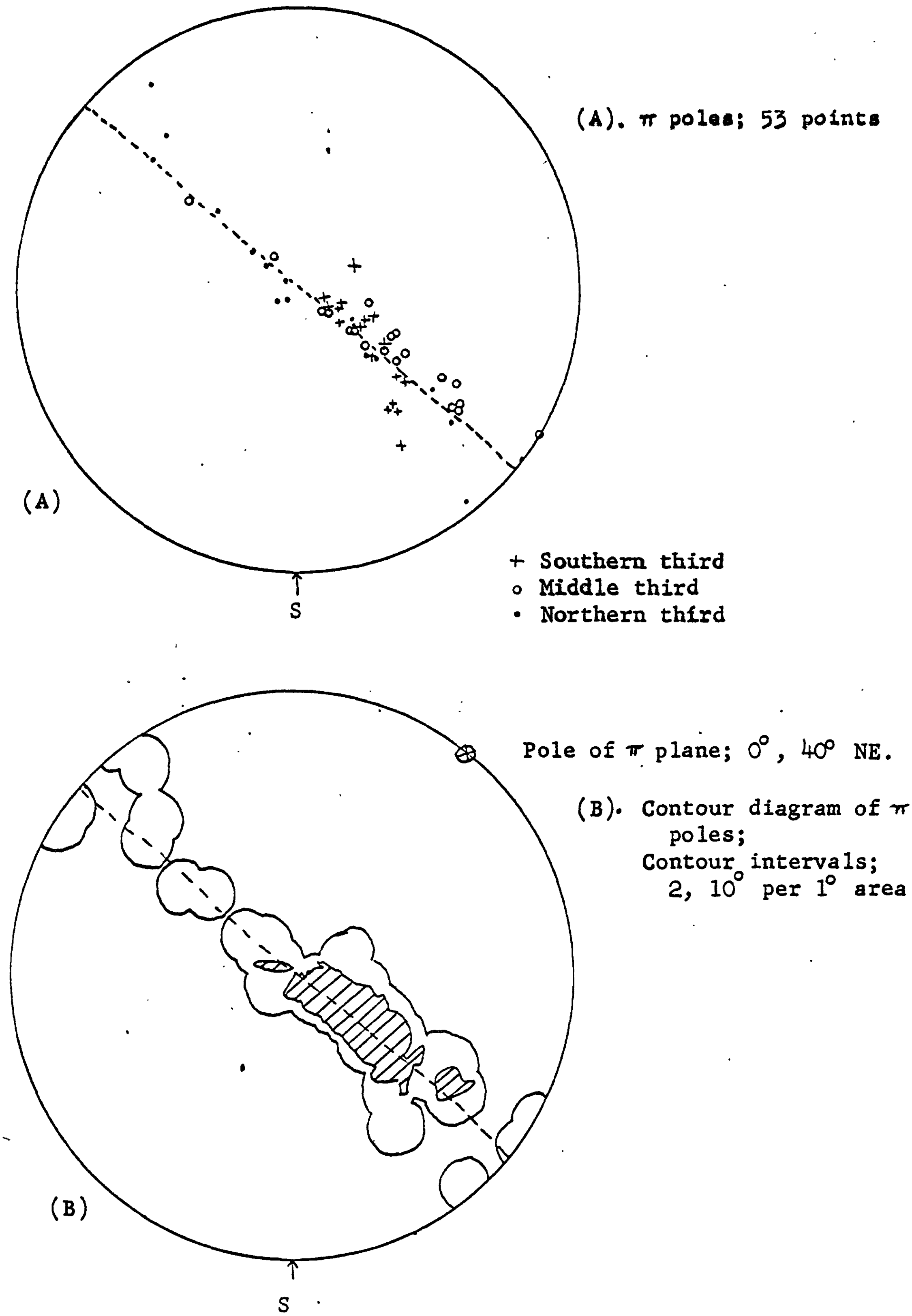
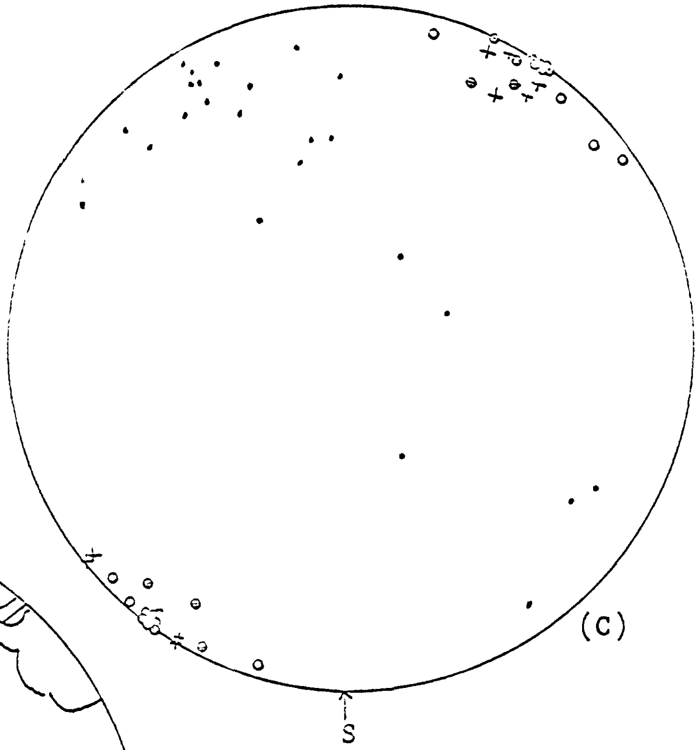


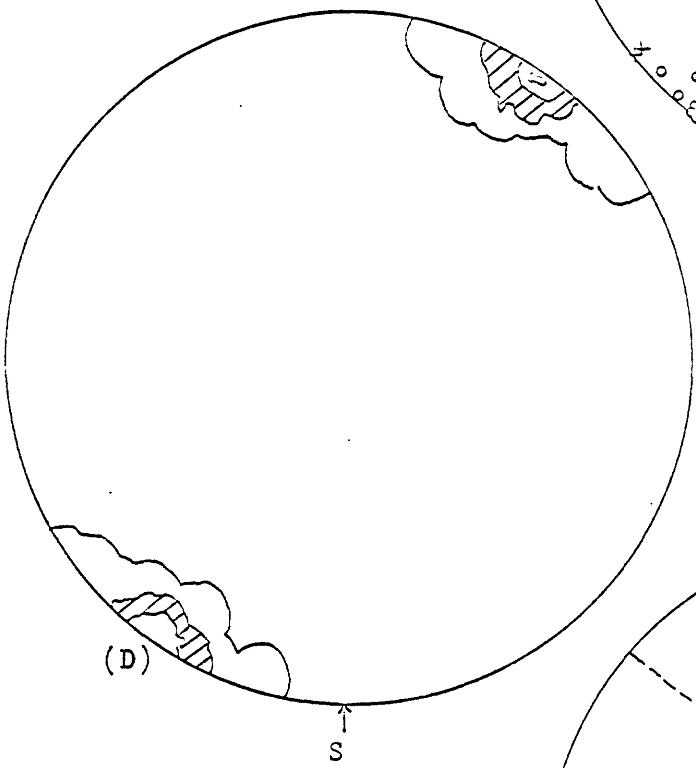
Figure 26.--Plot of π poles and lineations in the Hebron Formation in Day Brook, Danielson quadrangle (D-44.0-44.8N; 20.4W); plots are on the southern hemisphere of an equal area net.

(C). Lineations:
Mineral lineations
(24 points)
Crinkle lineations
(37 points)
Southern segment
Middle segment
Northern segment



(D). Contour diagram of crinkle lineations;
Contour intervals;
2.5, 8, 25, 40% per 1% area

B = 3°, 35° NE.



(E). Summary diagram

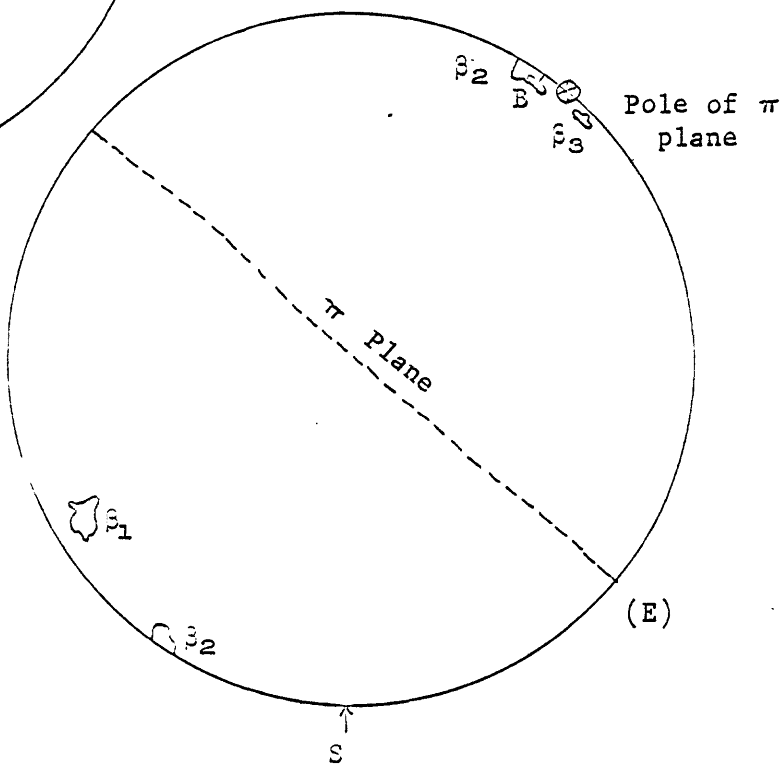


Figure 26.--Plot of π poles and lineations in Day Brook, Danielson quadrangle (continued)

AEROMAGNETICS

The state of Connecticut has been surveyed by an airborne magnetometer along east-west flight lines at 1/2 mile spacings, and the aeromagnetic contour maps for the Plainfield-Danielson area have been published by the U.S. Geological Survey (Boynton and Smith, 1965a and b; Philbin and Smith, 1966a and b). Specific use was made of the aeromagnetic map of the Plainfield and Danielson quadrangles as an aid in plotting some of the high-angle, northwest-trending faults. The magnetic evidence for these faults is mentioned earlier under the discussion of the faults.

The rocks of this area can be divided into two groups on the basis of their magnetic character. The Quinebaug Formation and the lower member of the Tatnic Hill Formation show the same complex magnetic pattern, typified by alternating linear magnetic highs and lows with a north-northeast trend. The magnetic pattern of these two units stops rather abruptly on both the east and west. On the west the sharp change in magnetic pattern follows very closely the contact between the lower member of the Tatnic Hill and the Fly Pond Member. All units east of, or stratigraphically above, this contact, including the Fly Pond and Yantic members of the Tatnic Hill, Hebron Formation, Scotland Schist and Canterbury and Eastford Gneisses, have the same, low level, featureless magnetic character. On the east the complex magnetic pattern of the Quinebaug Formation ends fairly abruptly along a line commonly 1/2 to 1 mile west of the trace of the Lake Char fault. The line of change is offset to the northwest in a few places, especially southwest of the village of Danielson, suggesting the fault may be offset locally by the northwest-trending faults. The Sterling Plutonic Group and the Plainfield Formation in the lower plate of the fault, are magnetically similar to the younger rocks of the area, and have a general low level, featureless magnetic character, although some of the Sterling biotite gneiss is slightly more magnetic, and the pure quartzites of the Plainfield Formation slightly less magnetic than the rest of the rocks. The character of the lower plate rocks is more clearly seen in the Oneco (Boynton and Smith, 1965c) and East Killingly (Philbin and Smith, 1966c) quadrangles than in the Danielson and Plainfield quadrangles, as the change in magnetic character occurs close to the quadrangle boundaries.

The only faults within the map area which are spcifically indicated by the aeromagnetic maps are the northwest-trending ones which offset the northeast-trending magnetic anomalies. The change in magnetic character along the east side of the Quinebaug Formation reflects the change in rock type across the Lake Char fault; the line of change apparently remains west of the fault trace because of the low angle of dip of the fault plane. The trend of anomalies in the Quinebaug is essentially parallel to the trend of the line of change in magnetic character, and individual anomalies are not sharply cut off along this line. There is, therefore, nothing on the aeromagnetic maps which specifically indicates that the change is the result of faulting rather than a normal stratigraphic or igneous contact between two rocks of differing magnetic character. There is no field evidence for a fault to the west where a similar change in magnetic character occurs along the contact between the lower member of the Tatnic Hill Formation and the Fly Pond member; the change here is probably due to original compositional differences in the rocks, although it could reflect mineralogic differences due to metamorphism. South of this area, in the Norwich and Uncasville quadrangles, the trace of the Honey Hill fault shows on the aeromagnetic maps (Boynton and Smith, 1965d and e) along a line which can be interpreted from the maps as a fault. The northeast-trending anomalies of the Tatnic Hill Formation in the upper plate are abruptly truncated along a general east-west trending line, while the low magnetic level rocks of the lower plate show broad anomalies parallel to the west-northwest trend of the Honey Hill fault and of the units south of it.

GEOLOGIC HISTORY

The history of the Plainfield-Danielson area apparently began in the Cambrian(?) with deposition of the clastic sediments of the Plainfield Formation. Some volcanic activity in the Cambrian is suggested by the hornblende gneisses which are associated with the metasedimentary rocks of the Plainfield Formation both in this area and more abundantly south of this area. The Plainfield Formation occurs only in the lower plate of the Lake Char thrust fault, and there is no record of deposition in the Plainfield-Danielson area between the Cambrian(?) sediments of the Plainfield and the middle Ordovician volcanic rocks of the Quinebaug Formation immediately above the fault plane.

Deposition of the volcanic and sedimentary rocks of the upper plate of the Lake Char fault probably began in the middle Ordovician and may have been confined to the Ordovician or may have continued into the lower Devonian. The middle Ordovician deposition started with a pile of volcanic sediments of the Quinebaug Formation, most of which were not locally derived, but came from a volcanic source outside this area, possibly to the north. No evidence of volcanic flows has been found in the area. Some non-volcanic sediments were probably intermixed with the volcanic sediments. Deposition of the calcic-sediments of the Black Hill Member probably represents a temporary hiatus in volcanic activity, although most of the sediments of the unit were probably reworked volcanic debris.

Above the Quinebaug Formation there is no evidence of further volcanic activity in the Plainfield-Danielson area, with the possible exception of some of the amphibolite pods in the lower part of the Tatnic Hill Formation. The sediments consisted of a thick sequence of graywackes, shales and siltstones and lesser amounts of interlayered calcareous siltstones and shales. Calcareous sediments predominated during deposition of the Fly Pond Member of the Tatnic Hill Formation and most of the Hebron Formation. The shales which formed the Scotland Schist were the youngest sediments now present in the area. All contacts between the various units appear to be conformable and so far as can be determined there were no depositional breaks in the sequence from Quinebaug Formation through the Scotland Schist. Along the western edge of eastern Connecticut the Taconic unconformity has been recognized along the west flank of the Monson anticline between the middle Ordovician Brimfield Formation and the Silurian and Devonian rocks of the Bolton Group of Rodgers et al (1959). The unconformity has not been recognized in the Plainfield-Danielson area at either possible comparable stratigraphic level; the Tatnic Hill and Hebron contact or the Hebron and Scotland contact. If there was a depositional break between any of these units, it is not now apparent. There is, however, fossil evidence in northeastern Maine (Pavlides and Berry, 1966), and in central Maine (Osberg et al, in preparation) of continuous deposition from the middle Ordovician through the upper Silurian on the east side of the Bronson Hill anticlinorium. It is possible, therefore, that the rocks east of the Monson anticline (part of the Bronson Hill anticlinorium) were originally deposited in an area which was not affected by the Taconic unconformity, and may represent continuous deposition from the middle Ordovician into the Silurian or the Devonian. The rocks of the upper plate of the Lake Char fault must have been originally deposited someplace to the west of the Plainfield-Danielson area, and were moved into their present position during thrusting along the Lake Char fault, and during the west to east movement of the overturning of the Hampton syncline.

The time of emplacement of the plutonic rocks is not well established. The sills of the Sterling Plutonic Group may have been emplaced during the middle Ordovician, and have been associated with the volcanic activity of that time, or they may have formed as late as the Devonian. The Canterbury and Eastford Gneisses have almost as large a possible time span for emplacement. The radiometric age determinations of the Canterbury suggest they crystallized in upper Ordovician or lower Silurian, while correlation with similar rocks in New Hampshire suggest they may have formed as late as middle to upper Devonian. The youngest rocks in the area are the small, unfoliated pegmatites which were probably formed during the Permian (Zartman et al, 1965). The small sill of gabbro in the Plainfield quadrangle (pl. 4) is probably an offshoot from the Preston Gabbro south of the Plainfield-Danielson area. Sclar (1958, p. 125) concluded that the Preston was emplaced after regional metamorphism of the surrounding rocks but prior to cataclasis, and reconnaissance in the Jewett City quadrangle confirms this conclusion.

The Plainfield-Danielson area has apparently been a highland since the end of the Paleozoic, and there is no record of either igneous activity or of deposition of sediments from the end of the Paleozoic to the Pleistocene. The area must have been uplifted prior to the early Mesozoic, as eastern Connecticut served as a source for the sediments deposited in the Connecticut valley during the Triassic (Rodgers et al, 1959). Diabase dikes of Triassic age cut the metamorphic rocks of the eastern highlands east of this area (Mikami and Digman, 1957; Snyder, 1967), but none have been found as far east as the Plainfield-Danielson area.

TECTONIC HISTORY

All rocks of the Plainfield-Danielson area, except a few small pegmatites and the gabbro sill, have been metamorphosed, folded and faulted during several stages of deformation. Evidences for repeated stages of deformation are given by the map pattern of the geologic units, particularly within eastern Connecticut as a whole (see pl. 1), by inverse relationships of metamorphic rocks, that is high grade rocks overlying lower grade rocks, by cataclastic deformation of metamorphic rocks, by folding and faulting of cataclastic rocks, by development of two sets of S surfaces and lineations in some rocks, and by different sets of small folds. The general sequence of events from oldest to youngest was (1) early folding, probably accompanied by metamorphism to high amphibolite facies, (2) refolding of the early formed fold system, and overturning from west to east, (3) cataclasis of rocks along the fault planes under middle amphibolite facies conditions and initial movement on the thrust faults, (4) formation of domes and basins and (5) high angle faulting. Probably (2) and (3) took place at about the same time, although either one may have started earlier than the other. How many of these events were continuing and overlapping effects of one major orogenic period, and how many were separate events cannot be determined as yet.

The earliest stage of folding resulted in the formation of the major folds of the area, including the Hampton-Chester-Hunts Brook syncline. The critical evidence for this fold system is southwest of the Plainfield-Danielson area, west of the Connecticut River and south of the Honey Hill fault (pl. 1; fig. 2). The time of regional metamorphism of the area is not well established, but it probably accompanied the early fold stage. Features in the Plainfield-Danielson area which relate to this stage of folding include some small scale folds, probably the moderate scale folds mapped in the Tatnic Hill Formation, S_1 foliations in the granitic gneisses and probably early foliations in the other rocks, and some, and possibly all mineral lineations. The axial attitudes of the early folds, prior to refolding, is not known; the folds were probably isoclinal.

In the second stage of folding the early formed Hampton-Chester-Hunts Brook syncline was refolded from west to east around the axial surface of the Selden Neck dome (see pl. 1; fig. 2). The Honey Hill-Lake Char fault surface is in the upper limb of the refolded fold, is subparallel to the axial surface of the refold, and has the same general sense of movement. It seems likely, therefore, that the west to east movement of the overturned fold and on the thrust fault took place at about the same time, and both may have taken place over a long period of time. Most of the prominent structural features of the area probably formed at this time, including the strong regional foliation, the regional north plunging lineation, most of the north plunging small scale folds, and cataclasis of the rocks near the thrust faults. Continued movement at later stages caused folding of the cataclastic rocks, formation of ultramylonite dikes cutting the cataclastic rocks, and mylonitization and brecciation in the axial zone and the upper limb of the overturned syncline. During this stage of folding high grade metamorphic rocks were placed over lower grade rocks, and metamorphic rocks were cataclastically deformed.

The final stage of folding could also have been a continuing effect of late stage movements on the thrust faults and of the eastward push of the syncline, or may have been a distinctly later event. It involved formation of the domes, such as the Willimantic dome, and basins as the Hopyard basin (fig. 2). In the Plainfield-Danielson area the late fold stage is reflected mainly in the shallow open syncline across the western part of the area, and in small, open folds within the area. The final stage of faulting, in which major movement was on the high angle faults, appears to have been the latest tectonic activity of the area and has offset all other structures, including the late, open folds. Minor movement on the thrust faults may have taken place at this time, but most of the thrust faults are apparently offset by the high angle faults.

By analogy with the rest of New England, the assumption has been commonly made that the major orogenic activity in eastern Connecticut took place during the Acadian orogeny in post lower Devonian time. There is, however, no direct evidence within Connecticut to date most of the tectonic activity. It is possible that the pre-Silurian rocks were folded in late Ordovician, during the Taconic orogeny, and Snyder (written communication, 1967) believes he has evidence for Taconic folding of the rocks below the unconformity between the Brimfield Schist and the Clough Quartzite. If Taconic folding did affect the pre-Silurian rocks, it has not yet been possible to distinguish these folds from late ones in areas away from the unconformity. The lower Devonian Littleton Formation in the core of the Great Hill syncline has been folded and regionally metamorphosed. The Great Hill syncline probably formed at the same time as the first stage of folding of the Hampton-Chester-Hunts Brook syncline. This would put an older limit of lower Devonian on the earliest known stage of folding. South of the Plainfield-Danielson area, dikes of Pennsylvanian or younger Westerly Granite cut the metamorphic rocks (Goldsmith, 1967; Feininger, 1965a and b) and are not themselves metamorphosed or deformed. The dikes have not been observed close to the Honey Hill-Lake Char fault system, so their age relative to the fault cannot be established. All rocks near the faults, including cross-cutting pegmatites have been cataclastically deformed. The Westerly dikes put a younger age limit of Pennsylvanian or Permian on the folding and metamorphism, but not necessarily on the faulting. Thus whether as one prolonged tectonic event or as two or more separate ones, deformation of the area must have taken place between lower Devonian and Permian. There is no evidence that the Triassic tectonism in the Connecticut valley west of eastern Connecticut had any effect at all east of the valley other than a few diabase dikes on the western side of the area. It is possible, however, that the high-angle faulting may have taken place as late as Triassic.

ECONOMIC GEOLOGY

The principal economic use of the rocks and minerals of this area in the past has been for various building and construction purposes, and the probabilities are that this will continue to be the main economic value of the rocks in the future. No minerals, either metallic or non-metallic have been mined or used from this part of eastern Connecticut. Small quarries are scattered throughout the area in almost all rock units, and the quarried rock was used either for dimension stone or for crushed rock.

One silver prospect was reported in southeastern Eastford in the Hampton quadrangle in the early 1800's. The only known reference to the prospect is in Mather (1834, p. 18), who was called in to examine the prospect. He determined that the ore was pyrite which, on analysis, showed no trace of silver. The prospect was probably in the thin belt of rusty weathering, pyritic muscovite schist in the Hebron Formation a few hundred feet south of Beaver Dam Brook, rather than near Silvermine Brook, as they are shown on the topographic map.

Bog iron ore was taken locally, though the largest local deposits were apparently in Woodstock to the northwest and Thompson to the northeast of the report area (Shepard, 1837). Mather (1834, p. 35) mentions bog iron in the town of Brooklyn, and the plot on his accompanying map indicates the deposit was in the area north of Gray Mare Hill in Danielson. He does not, however, give any information about the deposit, or indicate how long it was worked, or if, indeed, it was worked.

Minor sulfide minerals occur in many of the rock units of the area, but none are sufficient enough to suggest potentially economic amounts. Possibly some hydrothermal mineral deposits could have formed along the faults, especially the steep northwest trending faults in Plainfield and

Danielson, but there is no indication of mineral enrichment on the ground. The only metallic mineral found associated with the faults is small veins of quartz and magnetite, no more than an inch thick, in the tonalite gneiss of the Quinebaug Formation; the veins are locally pure magnetite. The veins were observed near the power line west of Alexander Lake (D-38.7N; 10.8W). The magnetite concentration in the area, however, is apparently rather low, as there is no increase in magnetic intensity of this area on the aeromagnetic map. A flight line was missed in this area, however, and there is a mile between flight lines here. The intervening half-mile flight would have gone almost directly over the area where the magnetite veins occur, and possibly a small local magnetic high would have been generated had the half-mile line been flown. The aeromagnetic map does, however, indicate that magnetite concentration in the area is not large enough to suggest a possible economic deposit.

The vein quartz along the Lake Char fault, or a branch off the main thrust, in the southern part of the Plainfield quadrangle is of possible economic value, though again, is probably too limited in size. It is similar to the vein quartz on Lantern Hill south of the Preston Gabbro, which is currently being mined for use in silica glass. The vein quartz on Lantern Hill is, however, a large, massive body about 1 mile long and 1/4 mile wide, that forms a topographic high. The exposure in the Plainfield quadrangle is about 20 feet long and 5 feet wide, and is located on a valley side with no topographic expression of its own. The exposed quartz is, therefore, probably about all the vein quartz there is at the locality, and is not enough to be economically exploited. Loughlin (1912) describes and plots on the map several other small bodies of vein quartz east and south of the Preston Gabbro, but does not mention any attempt to mine them.

Field stones of all rock types have been used since colonial days for building foundations, paving stones and similar building purposes. Rocks were quarried from the Canterbury and Eastford Gneisses and the Quinebaug Formation, as well as some of the larger pegmatite bodies for such use and for other construction purposes, such as dams and bridge supports. The quarries are all small and none are mentioned by Dale and Gregory (1911) so all use must have been for local use. A few small quarries in the slabby rocks, as the Hebron and Quinebaug Formations, still provide slabs for flagstone. The only quarry currently operating on a full time basis is in the cataclastic Quinebaug Formation in southern part of the Danielson quadrangle. The quarry is operated in conjunction with the large gravel quarries south of Quinebaug Pond, and the rock is crushed and probably used for highway fill. Other abandoned quarries in the Quinebaug and Tatnic Hill Formations were probably also quarried for crushed rock.

The Indians of the area quarried mylonitized Hope Valley Alaskite and Plainfield Formation for use as whetstones. Their principal quarries were along Whetstone Brook on the eastern edge of the Danielson quadrangle and western edge of the East Killingly quadrangle (Larned, 1874). The mylonites and blastomylonites are extremely hard, dense rocks and possibly could be a potential source of grinding stones. There is no known reference to their use as such since the time of the Indians, though Mather (1834) mentions quarrying of some noncataclastic Plainfield Formation in the East Killingly quadrangle for whetstones.

References cited

Aitken, J. M., 1951, Geology of a section of the Hebron Gneiss of eastern Connecticut: Connecticut Geol. Nat. History Survey Bull. 78, 55 p.

__________, 1955, The bedrock geology of the Rockville quadrangle, with map: Connecticut Geol. Nat. History Survey Quad. Rpt. no. 6, 55 p.

Albee, A. L., 1965, Phase equilibria in three assemblages of kyanite-zone pelitic schists, Lincoln Mountain quadrangle, Central Vermont: Jour. of Petrology, v. 6, no. 2, p. 246-301.

American Geological Institute, 1957, Glossary of geology and related sciences: Nat'l. Research Council Pub. 501, 325 p.

Barrel, Joseph, and Loughlin, G. F., 1910, The lithology of Connecticut: Connecticut Geol. Nat. History Survey Bull. 13, 207 p.

Barth, T. F. W., 1959, Principles of classification and norm calculations of metamorphic rocks: Jour. Geology, v. 63, p. 135-152.

__________, 1962, A final proposal for calculating the mesonorm of metamorphic rocks: Jour. Geology, v. 70, p. 497-498.

Billings, M. P., 1956, The geology of New Hampshire, pt. II, Bedrock geology: New Hampshire Planning and Dev. Comm., 200 p.

Billings, M. P., and Wilson, R. J., 1964, Chemical analyses of rocks and rock-minerals from New Hampshire: New Hampshire Div. of Economic Development, Mineral Res. Survey, pt. 19, 104 p.

Boucot, A. J., and Arndt, R., 1960, Fossils of the Littleton Formation (lower Devonian), New Hampshire: U. S. Geol. Survey Prof. Paper 334B, p. B41-B51.

Boucot, A. J., and Thompson, J. B., Jr., 1963, Metamorphosed Silurian brachiopods from New Hampshire: Geol. Soc. Am. Bull., v. 74, no. 11, p. 1313-1332.

Boynton, G. R., and Smith, C. W., 1965a, Aeromagnetic map of the Scotland quadrangle, Windham and New London Counties, Connecticut: U. S. Geol. Survey Geophysical Inv. Map GP-540.

__________, 1965b, Aeromagnetic map of the Plainfield quadrangle, New London and Windham Counties, Connecticut: U. S. Geol. Survey Geophysical Inv. Map GP-541.

__________, 1965c, Aeromagnetic map of the Oneco quadrangle, Connecticut and Rhode Island: U. S. Geol. Survey Geophysical Inv. Map GP-542.

__________, 1965d, Aeromagnetic map of the Norwich quadrangle, New London County, Connecticut: U. S. Geol. Survey Geophysical Inv. Map GP-543.

__________, 1965e, Aeromagnetic map of the Uncasville quadrangle and part of the New London quadrangle, New London County, Connecticut: U. S. Geol. Survey Geophysical Inv. Map GP-546.

Brookins, D. G., and Hurley, P. M., 1965, Rb-Sr geochronological investigations in the Middle Haddam and Glastonbury quadrangles, eastern Connecticut: Am. Jour. Sci., v. 263, p. 1-16.

Bryant, Bruce, 1966, Formation of phyllonites in the Grandfather Mountain area, northwestern North Carolina, in Geol. Survey Research, Short Papers in the geologic and hydrologic sciences: U. S. Geol. Survey Prof. Paper 550-D, p. D144-D150.

Bryant, Bruce, and Reed, J. C., Jr., in press, The geology of the Grandfather Mountain Window and vicinity, North Carolina-Tennessee: U. S. Geol. Survey Prof. Paper 615.

Cady, W. M., 1960, Stratigraphic and geotectonic relationships in northern Vermont and southern Quebec: Geol. Soc. Am. Bull., v. 71, p. 531-576.

Callaghan, Eugene, 1931, A contribution to the structural geology of central Massachusetts: Annals of New York Acad. of Sci., v. 38, p. 27-75.

Chayes, Felix, 1952, The finer-grained calcalkaline granites of New England: Jour. of Geology, v. 60, no. 3, p. 207-254.

Christie, J. M., 1960, Mylonitic rocks of the Moine Thrust-zone in the Assynt Region, North West Scotland: Edinburgh Geol. Soc., v. 18, pt. 1, p. 79-93.

Collins, G. B., 1954, The bedrock geology of the Ellington quadrangle, with map: Connecticut Geol. Nat. History Survey Quadrangle Rpt. no. 4, 44 p.

Dale, T. N., and Gregory, H. E., 1911, The granites of Connecticut: U. S. Geol. Survey Bull. 484, 137 p.

Dana, E. S., 1899, System of mineralogy: Wiley, New York, Ed. 6., 1134 p.

Dixon, H. R., 1964, The Putnam Group of eastern Connecticut: U. S. Geol. Survey Bull. 1194-C, p. C1-C12.

Eaton, G. P., and Rosenfeld, J. L., 1960, Gravimetric and structural investigations in central Connecticut: Internat. Geol. Congress, XXI Session, Norden, 1960 Part II, p. 168-177.

Emerson, B. K., 1898, Geology of Old Hampshire County, Massachusetts, comprising Franklin, Hampshire and Hampden counties: U. S. Geol. Survey Mon. 29, 782 p.

__________, 1917, Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, 289 p.

Engel, A. E. J., and Engel, C. G., 1960, Progressive metamorphism and granitization of the major paragneiss, northwest Adirondack Mountains, New York, Part II: Mineralogy: Geol. Soc. Am., Bull., v. 71, no. 1, p. 1-57.

Faul, Henry, Stern, T. W., Thomas, H. H., and Elmore, P. L. D., 1963, Ages of intrusion and metamorphism in the northern Appalachian: Am. Jour. Sci., v. 261. p. 1-19.

Feininger, Tomas, 1965a, Bedrock geologic map of the Ashaway quadrangle, Connecticut and Rhode Island: U. S. Geol. Survey Quad. Map GQ-403.

__________, 1965b, Bedrock geologic map of the Voluntown quadrangle, Connecticut and Rhode Island: U. S. Geol. Survey Quad. Map GQ-436.

Foye, W. G., 1949, The geology of eastern Connecticut: Connecticut Geol. Nat. History Survey Bull. 74, 95 p.

Foye, W. G., and Lane, A. C., 1934, Correlations by radioactive minerals in the metamorphic rocks of southern New England: Am. Jour. Sci., Fifth Series, v. 27, no. 164, p. 127-138.

Goddard, E. N., and others, 1948, Rock color chart: Washington D. C., Nat'l. Research Council, 6 p.

Goldsmith, Richard, 1961, Axial plane folding in southeastern Connecticut, _in_ Short Papers in the Geologic and Hydrologic Sciences: U. S. Geol. Survey Prof. Paper 424-C, p. C54-C57.

__________, 1963, Geologic sketch map of eastern Connecticut: U. S. Geol. Survey open-file report.

__________, 1966, Stratigraphic names in the New London area Connecticut: U. S. Geol. Survey Bull. 1224-J, p. J1-J9.

__________, 1967a, Bedrock geology of the Uncasville quadrangle, New London County, Connecticut: U. S. Geol. Survey Quad. Map GQ-576.

__________, 1967b, Bedrock geologic map of the Montville quadrangle, New London County, Connecticut: U. S. Geol. Survey Quad. Map GQ-609.

__________, 1967c, Bedrock geology of the New London quadrangle, New London County, Connecticut: U. S. Geol. Survey Quad. Map GQ-574.

Goldsmith, Richard, 1967d, Bedrock geology of the Niantic quadrangle, New London County, Connecticut: U. S. Geol. Survey Quad. Map GQ-575.

Green, J. C., 1963, High-level metamorphism of pelitic rocks in northern New Hampshire: Am. Mineralogist, v. 48, no. 9 and 10, p. 991-1023.

Gregory, H. E., and Robinson, H. H., 1907, Preliminary geologic map of Connecticut: Connecticut Geol. Nat. History Survey Bull. 7, 39 p.

Harwood, David S., 1967, Fossiliferous pre-Silurian and Silurian rocks in the Cupsuptic quadrangle, west-central Maine /Abs./: Geol. Soc. Am., Northeastern Section, Boston, Massachusetts, p. 33.

Hatch, N. L., Jr., 1963, The geology of the Dixville quadrangle, New Hampshire: New Hampshire Dept. Res. and Economic Development, Bull. 1, 81 p.

Herz, Norman, 1955, The bedrock geology of the Glastonbury quadrangle, with map: Connecticut Geol. Nat. History Survey Quad. Rpt. no. 5, 22 p.

Hill, T. P., Werner, M. A., and Horton, M. J., 1967, Chemical composition of sedimentary rocks in Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming: U. S. Geol. Survey Prof. Paper 561, 241 p.

Holmes, Arthur, 1960, A revised geological time scale: Edinburgh Geol. Soc., Trans., v. 17, pt. 3, p. 204.

Knopf, E. B., 1931, Retrogressive metamorphism and phyllonitization: Am. Jour. Sci., Fifth Series, v. 21, no. 121, p. 1-27.

__________, 1935, Recognition of overthrusts in metamorphic terranes: Am. Jour. Sci., Fifth Series, v. 30, no. 177, p. 198-209.

Kulp, J. L., 1961, Geologic time scale: Science, v. 133, no. 3459, p. 111.

Lapworth, Charles, 1885, The Highland Controversy in British Geology: Nature, v. XXXII, p. 558-559.

Larned, E. D., 1874, History of Windham County, Connecticut: Worcester, Massachusetts, Chas. Hamilton, 600 p.

Loughlin, G. F., 1912, The gabbros and associated rocks at Preston, Connecticut: U. S. Geol. Survey Bull. 492, 158 p.

Lundgren, Lawrence, Jr., 1962, Deep River area, Connecticut; stratigraphy and structure: Am. Jour. Sci., v. 260, p. 1-23.

__________, 1963, The bedrock geology of the Deep River quadrangle, with map: Connecticut Geol. Nat. History Survey Quad. Rpt. no. 13, 40 p.

__________, 1964, The bedrock geology of the Essex quadrangle, with map: Connecticut Geol. Nat. History Survey Quad. Rpt. no. 15, 36 p.

__________, 1966a, The Bedrock geology of the Hamburg quadrangle, Connecticut: Connecticut Geol. Nat. History Survey Quad. Rpt. no. 19, 41 p.

__________, 1966b, Muscovite reactions and partial melting in southeastern Connecticut: Jour. of Petrology, v. 7, no. 3, p. 421-453.

__________, 1967, The bedrock geology of the Old Lyme quadrangle: Connecticut Geol. Nat. History Survey Quad. Rpt. no. 21, 30 p.

Lundgren, Lawrence, Jr., Goldsmith, Richard, and Snyder, G. L., 1958, Major thrust fault in southeastern Connecticut [Abs.]: Geol. Soc. Am. Bull., v. 69, no. 12, pt. 2, p. 1606.

Martin, L. H., 1925, The geology of the Stonington region, Connecticut: Connecticut Geol. Nat. History Survey Bull. no. 33, 70 p.

Mather, W. W., 1834, Sketch of the geology and mineralogy of New-London and Windham counties in Connecticut: Norwich, Connecticut, Wm. Lester, Jr., 36 p.

Mikami, H. M., and Digman, R. E., 1957, The bedrock geology of the Guilford 15-minute quadrangle and a portion of the New Haven quadrangle: Connecticut Geol. Nat. History Survey Bull. 86, 99 p.

Moore, G. E., Jr., 1958, Bedrock geology of the Hope Valley quadrangle, Rhode Island: U. S. Geol. Survey Quad. Map GQ-105.

__________, 1967, Bedrock geologic map of the Watch Hill quadrangle, Washington County, Rhode Island and New London County, Connecticut: U. S. Geol. Survey Quad. Map GQ-655.

Niggli, Paul, 1954, Rocks and mineral deposits: San Francisco, California, W. H. Freeman and Co., 559 p.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. Am., v. 65, no. 10, p. 1007-1032.

Novotny, R. F., 1961, A regional fault in east-central Massachusetts and southern New Hampshire, in Short Papers in the Geologic and Hydrologic Sciences: U. S. Geol. Survey Prof. Paper 424-D, p. D48-D49.

Osberg, P. H., 1967, Stratigraphy, structural geology, and metamorphism in the Waterville-Vassalboro area, Maine: Maine Geol. Survey Quad. Mapping Series no. 4.

Pavlides, Louis, and Berry, W. B. N., 1966, Graptolite-bearing Silurian rocks of the Houlton-Smyrna Mills area, Aroostook County, Maine, in Short Papers in the Geologic and Hydrologic Sciences: U. S. Geol. Survey Prof. Paper 550-B, p. B51-B61.

Peper, J. D., 1967, Stratigraphy and structure of the Monson area, Massachusetts and Connecticut, in New England Intercollegiate Geol. Conference Guidebook, 59th Annual Meeting, Amherst, Massachusetts: p. 105-114.

Percival, J. G., 1842, Report on the geology of the State of Connecticut: New Haven, Connecticut, Osborn and Baldwin, 495 p.

Perhac, R. M., 1958, Petrogenesis of the Voluntown and Oneco quadrangles: Connecticut Geol. Nat. History Survey Bull. no. 89, 27 p.

Pessl, Fred, Jr., 1966, a two-till locality in northeastern Connecticut, in Short Papers in the Geologic and Hydrologic Sciences: U. S. Geol. Survey Prof. Paper 550-D, p. D89-D93.

Pettijohn, F. J., 1957, Sedimentary rocks: New York, Harper and Brothers, Second Edition, 718 p.

__________, 1963, Chemical composition of sandstone--excluding carbonate and volcanic sands: U. S. Geol. Survey Prof. Paper 440-S, 21 p.

Philbin, P. W., and Smith, C. W., 1966a, Aeromagnetic map of the Danielson quadrangle and part of the Plainfield quadrangle, Windham County, Connecticut: U. S. Geol. Survey Geophysical Inv. Map GP-592.

__________, 1966b, Aeromagnetic map of the Hampton quadrangle and part of the Scotland quadrangle, Windham County, Connecticut: U. S. Geol. Survey Geophysical Inv. Map GP-593.

__________, 1966c, Aeromagnetic map of the East Killingly quadrangle and part of the Oneco quadrangle, Connecticut and Rhode Island: U. S. Geol. Survey Geophysical Inv. Map GP-591.

Quensel, Percy, 1916, Zur Kenntnis der Mylonitbildung: The Geol. Inst. of the University of Upsala, Bull. v. XV, p. 91-116.

Quinn, A. W., 1951, Bedrock Geology of the north Scituate quadrangle, Rhode Island: U. S. Geol. Survey Quad. Map GQ-13.

Randall, A. D., Thomas, M. P., Thomas, C. E., Jr., and Baker, J. A., 1966, Water resources inventory of Connecticut, Part I Quinebaug River Basin: Connecticut Water Resources Bull. no. 8, 101 p.

Rice, W. N., and Gregory, H. E., 1906, Manual of the geology of Connecticut: Connecticut Geol. Nat. History Survey Bull. no. 6, 273 p.

Robinson, Peter, 1967, Gneiss domes and recumbent folds of the Orange area, west-central Massachusetts, in New England Intercollegiate Geol. Conference Guidebook, 59th Annual Meeting, Amherst, Massachusetts: p. 17-47.

Rodgers, John, Gates, R. M., Cameron, E. N., and Ross, R. J., 1956, A preliminary geological map of Connecticut: Connecticut Geol. Nat. History Survey.

Rodgers, John, Gates, R. M., and Rosenfeld, J. L., 1959, Explanatory text for preliminary geological map of Connecticut, 1956: Connecticut Geol. Nat. History Survey Bull. no. 84, 64 p.

Sander, Bruno, 1912, Über einige Gesteinsgruppen des Tauernwestendes: Geol. Reichsanst. Jahrbuch, v. 62, p. 249-257.

Sclar, C. B., 1958, The Preston Gabbro and the associated metamorphic gneisses New London County, Connecticut: Connecticut Geol. Nat. History Survey Bull. no. 88, 31 p.

Shaler, N. S., Woodworth, J. B., and Foerste, A. F., 1899, Geology of the Narragansett Basin: U. S. Geol. Survey Mon. 33, 402 p.

Shaw, D. M., 1956, Geochemistry of pelitic rocks, Part III: Major elements and general geochemistry: Geol. Soc. Am., Bull. v. 67, no. 7, p. 919-934.

Shephard, C. U., 1837, A report on the Geol. Survey of Connecticut: New Haven, Connecticut, B. L. Hamlen, 188 p.

Snyder, G. L., 1961, Bedrock geology of the Norwich quadrangle, Connecticut: U. S. Geol. Survey Quad. Map GQ-144.

__________, 1964a, Petrochemistry and bedrock geology of the Fitchville quadrangle, Connecticut: U. S. Geol. Survey Bull. 1161-I, 164 p.

Snyder, G. L., 1964b, Bedrock geology of the Willimantic quadrangle, Connecticut: U. S. Geol. Survey Quad. Map GQ-335.

__________, 1967, Bedrock geologic map of the Columbia quadrangle, east-central Connecticut: U. S. Geol. Survey Quad. Map GQ-592.

Sohon, J. A., 1951, Connecticut minerals; their properties and occurrence: Connecticut Geol. Nat. History Survey Bull. no. 77, 128 p.

Thomas, C. E., Jr., Randall, A. D., and Thomas, M. P., 1966, Hydrogeologic data in the Quinebaug River basin, Connecticut: State of Connecticut Water Resources Commission Bull. no. 9, 83 p.

Thompson, J. B., Jr., 1957, The graphical analysis of mineral assemblages in pelitic schists: Am. Mineralogist, v. 42, p. 842-858.

Tröger, W. E., 1956, Optische Bestimmung der gesteinsbildenden: Stuttgart, Germany, Minerale, 147 p.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O: Geol. Soc. Am. Mem. 74., 153 p.

Waters, A. C., and Campbell, C. D., 1935, Mylonites from the San Andreas fault zone: Am. Jour. Sci., Fifth Series, v. 24, no. 174, p. 473-503.

White, David, 1912, Age of the Worcester phyllite: Washington Acad. of Sci. Jour., v. 2, p. 114-118.

Wilcox, R. E., 1959, Use of the spindle stage for determination of principal indices of refraction of crystal fragments: Am. Mineralogist, v. 44, no. 11 and 12, p. 1272-1293.

Wilcox, Ray E., and Izett, Glen A., 1968, Optic angle determined conoscopically on the spindle stage: I. Micrometer ocular methods: Am. Mineralogist, v. 53, no. 1 and 2, p. 269-289.

Zartman, Robert, Snyder, George, Stern, T. W., Marvin, R. F., and Bucknam, R. C., 1965, Implications of new radiometric ages in eastern Connecticut and Massachusetts, in Short Papers in the Geologic and Hydrologic Sciences: U. S. Geol. Survey Prof. Paper 525-D, p. D1-D10.

Plate 7.--Progressive cataclasis of quartzite of the Plainfield Formation.

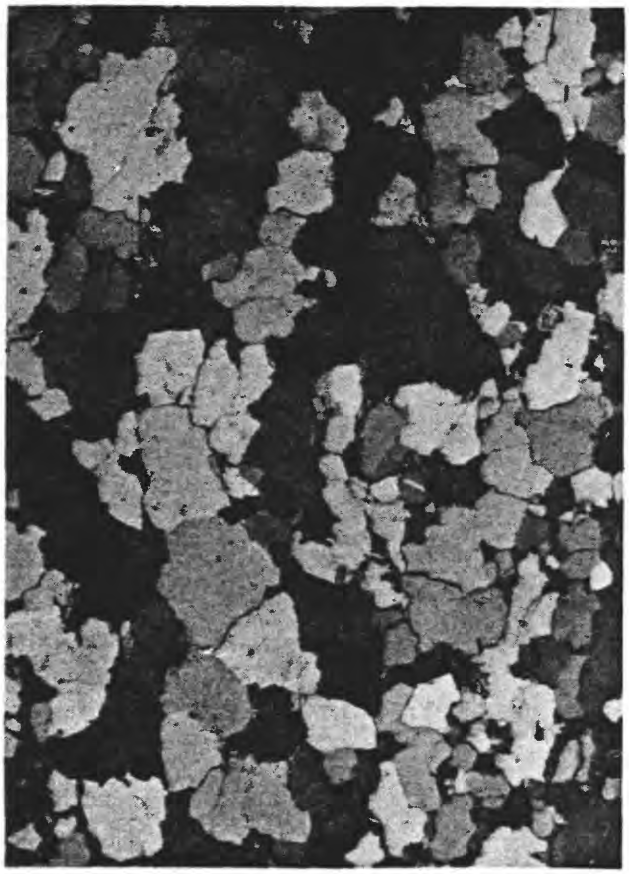
1. Noncataclastic quartzite from the Thompson quadrangle. Grains are essentially equigranular, and most have smooth boundaries. The average grain size is about 0.7 mm. (T2-3; T-12.4N; 14.3W).

2. Cataclastic quartzite. Grains are elongated parallel to the cataclastic foliation and have moderately sutured boundaries. Average grain size is 0.1 mm. (P2-262; P-30.8N; 0.6W).

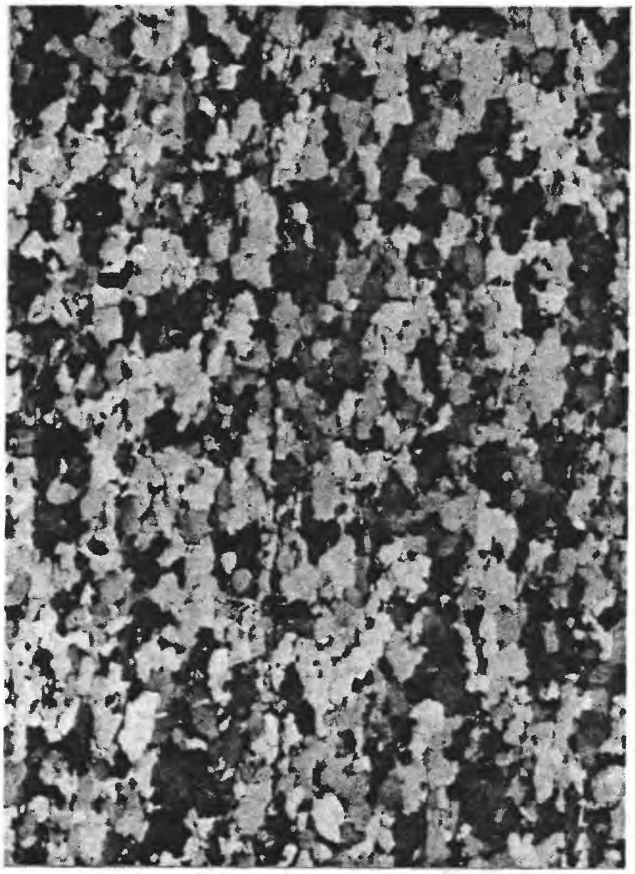
3. Quartzite mylonite. Sample was collected a few inches below the Lake Char thrust fault. Grains are elongated parallel to the cataclastic foliation. Average grain size is about 0.03 mm. (P2-382; P-43.0N; 0.7W).

4. Quartzite mylonite. Sample was collected on the fault contact between quartzite and hornblende gneiss of the Plainfield Formation exposed in cuts on the Connecticut Turnpike in the East Killingly quadrangle. The very-fine-grained matrix in the right half of the photograph is a mixture of quartz and unidentified material, and contains clasts of quartz and of mylonitized quartzite. Quartz grains on the left side of the photograph are recrystallized and are strongly sutured. (E3-43; E-33.6N; 4.5N).

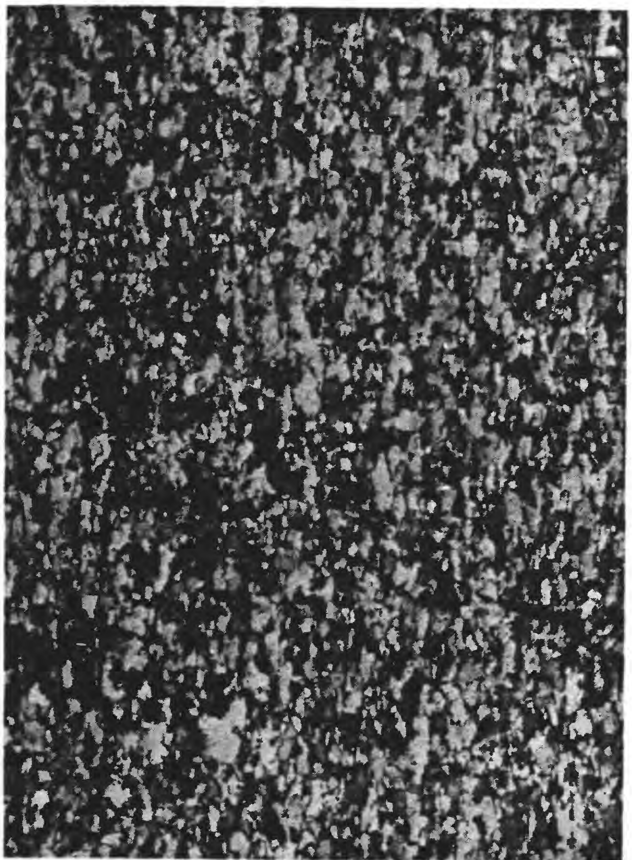
(All photos taken with crossed nicols; magnification 31x.)



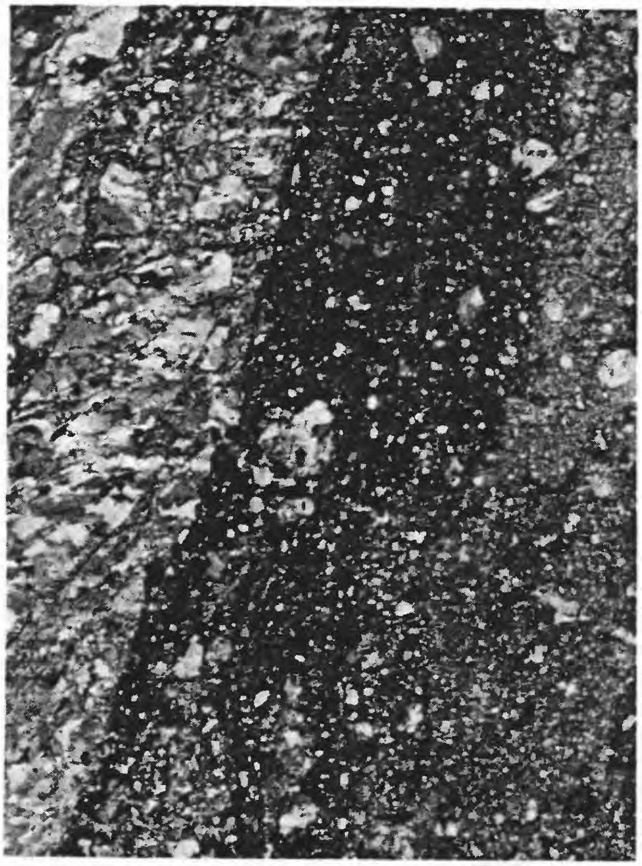
7-1



7-2



7-3



7-4

Plate 8.--Details of mylonite fabric in the Plainfield Formation.

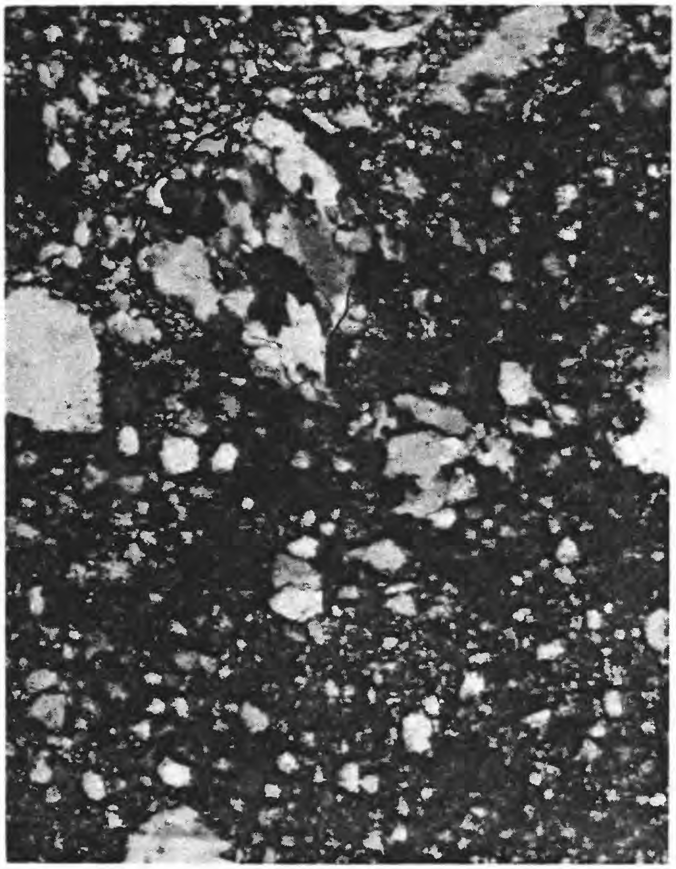
1. Enlargement of the quartzite mylonite of plate 7-4. A clast of quartzite mylonite, containing fine-grained, sutured quartz and minor potassium feldspar, is outlined. (E3-46; crossed nicols; magnification 100x.)

2. Same as 8-1 in plane light.

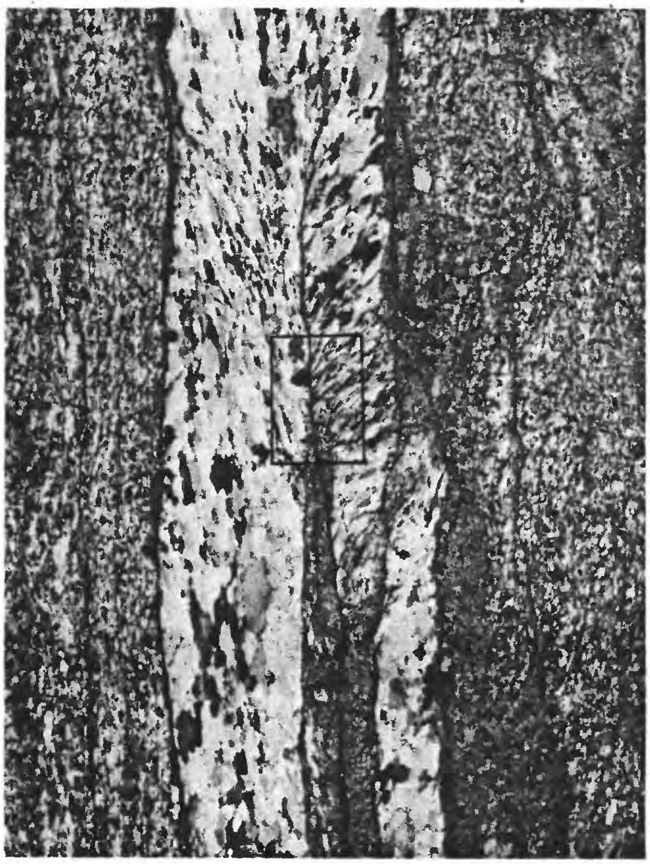
3. Quartz schist mylonite. Laminae on both sides of the photo consist of very-fine-grained quartz, biotite and sericite. Center lamina is fine-grained, recrystallized, strongly sutured quartz. A few clasts of plagioclase are uncrushed. Thin streaks separating and within laminae are shear planes; the one in the center of the photo dies out near the top of the photo. (D3-31; D-33.5N; 1.1W, a core sample from exploratory drilling for a new highway; crossed nicols; magnification 11.2x.)

4. Enlargement of the area outlined in the center of 8-3, showing details of the recrystallized quartz. (Crossed nicols; magnification 70x.) (See also plate 17-3.)

(k - potassium feldspar; p - plagioclase).



8-1. 0 1 mm 8-2.



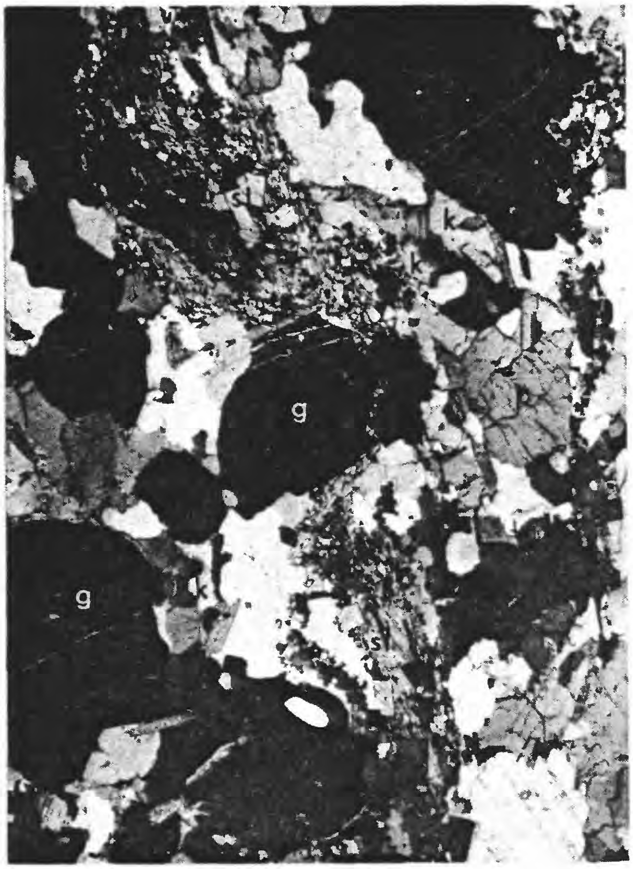
8-3. 0 1 2 mm

0 8-4. 1 mm

Plate 9.--Progressive cataclasis of the sillimanite gneiss unit of the Tatnic Hill Formation.

1. Noncataclastic sillimanite-gneiss. Streaks of fine- to very-fine-grained sillimanite are subparallel to the biotite orientation. Quartz is in granular grains with regular boundaries. Microcline occur in fine grains. (S8-121; S-10.7N; 0.7W).
2. Mortared sillimanite gneiss. Streaks of granulated quartz, biotite and plagioclase are parallel to the mica orientation. Quartz grains are variable in size and show moderate suturing. Plagioclase grains are somewhat fractured, but the boundaries are not commonly granulated. (S8-126; S-7.8N; 4.5W).
3. Mylonitic sillimanite gneiss. Quartz is in streaks of fine- to very-fine, sutured grains. The streaks are separated by very-fine-grained biotite, quartz and plagioclase. The only ungranulated biotite is in the lee of, or as inclusions in garnet. Sillimanite occurs in fine to small euhedral grains which are not granulated; garnet also is not granulated. Plagioclase grains have been rounded by granulation along the grain boundaries. (P1-82; P-15.4N; 28.7W).
4. Same as 9-3 in plane light.

(9-1, 9-2, 9-3 are crossed nicols, 9-4 is plane light; magnification 20x ; g - garnet; p - plagioclase; sl - sillimanite; b - biotite; q - quartz; k - potassium feldspar; m - muscovite; r - rutite; b-q - very-fine-grained biotite and quartz.)



9-1.

0 1 2 mm

9-2.

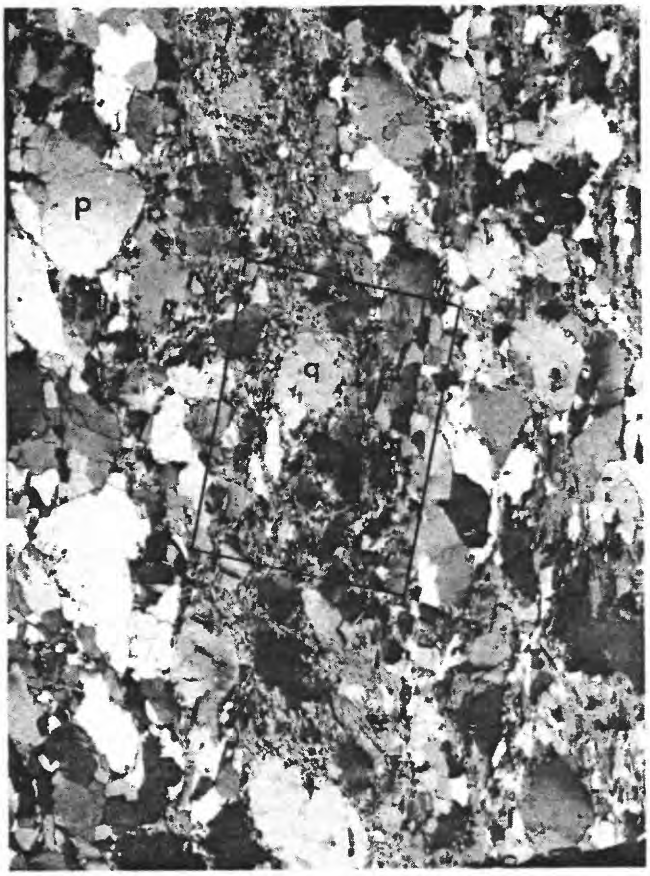
9-3.

9-4.

Plate 10.--Details of cataclasis in gneisses of the lower member of the Tatnic Hill Formation.

1. Mortar gneiss, garnet-biotite gneiss unit. Streaks of granulated quartz, biotite and plagioclase surround and separate areas of ungranulated grains. Grains are variable in size from small to very fine. Some plagioclase grains have bent twin lamellae, and most have granulated boundaries. Quartz in the granulated streaks is moderately sutured. (P1-57; P-4.6N; 32.5W; crossed nicols; magnification 16x.)
2. Enlargement of the area outlined in the center of 10-1. (Crossed nicols; magnification 48x.)
3. Mylonite, garnet-biotite gneiss unit. Uniformly very-fine-grained, granulated rock. Subhedral garnet grains are slightly rounded but are in general not granulated. The very fine grains are strung out in thin laminae separated by thin streaks of sericite and granulated biotite. In the upper left hand corner is a streak of mixed biotite, sericite, quartz and plagioclase. Some plagioclase is fresh and some is completely sericitized. The laminae are crinkled around the garnet and plagioclase grains. (P-95; P-17.9N; 32.1W; crossed nicols, magnification 15x.)
4. Same as 10-3 in plane light.

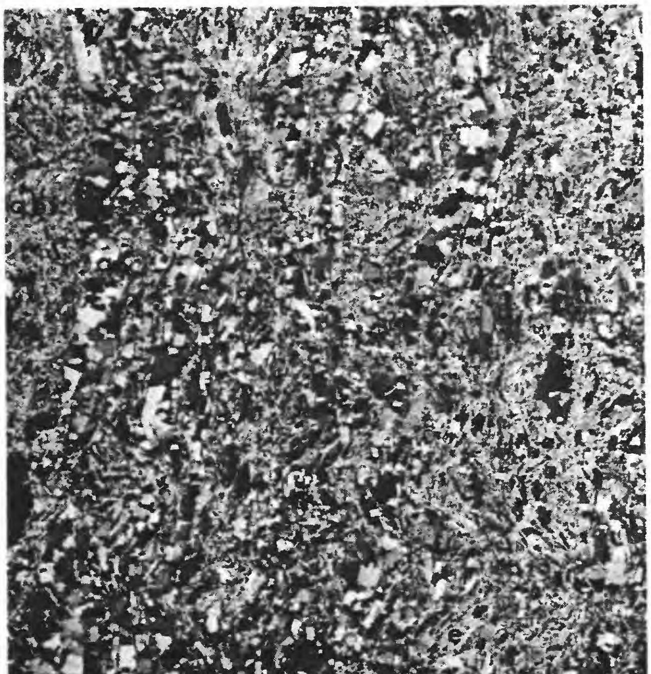
(p - plagioclase; ps - sericitized plagioclase; q - quartz; b - biotite; qbf - granulated quartz, biotite and feldspar; g - garnet; e - epidote.)

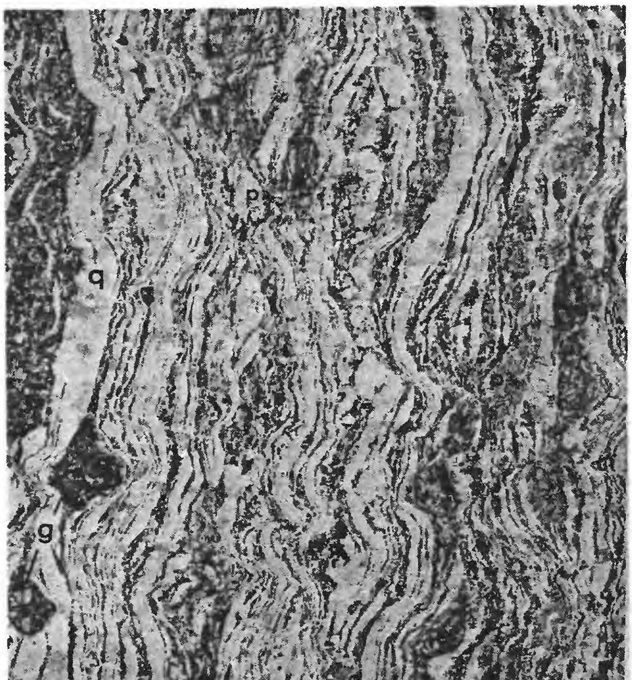


0 1 mm

10-1.

0 1 mm 10-2.





0 1 mm

10-3.

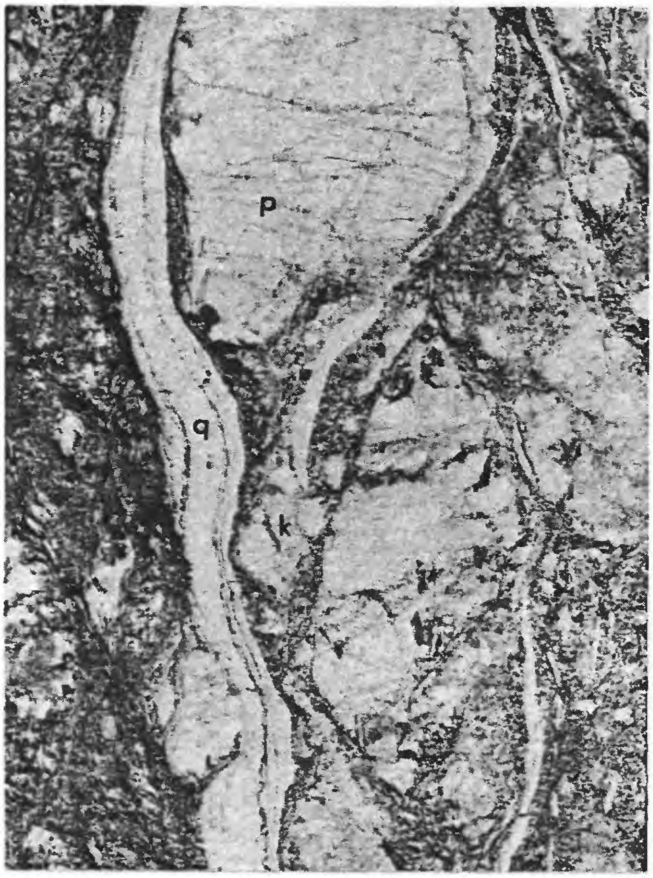
10-4.

Plate 11.--Mylonite gneiss of the garnet-biotite gneiss unit in the Tatnic Hill Formation.

1. Porphyroclasts of plagioclase and, less abundantly microcline and garnet, in a very-fine-grained matrix of quartz, feldspar and biotite. Streaks of granulated and strongly sutured quartz are warped around the coarse feldspars. (Crossed nicols).
2. Same as 11-1 in plane light.
3. Similar to 11-1. The streak of very-fine, sutured quartz across the center of the photo is continuous with the larger one across 11-1. Garnet is apparently broken. (Crossed nicols).
4. Same as 11-3 in plane light.

(Pl-124; P-30.2N; 26.0W; magnification 16x; p - plagioclase; k - microcline; q - quartz; qbf - granulated quartz, biotite and feldspar; g - garnet.)

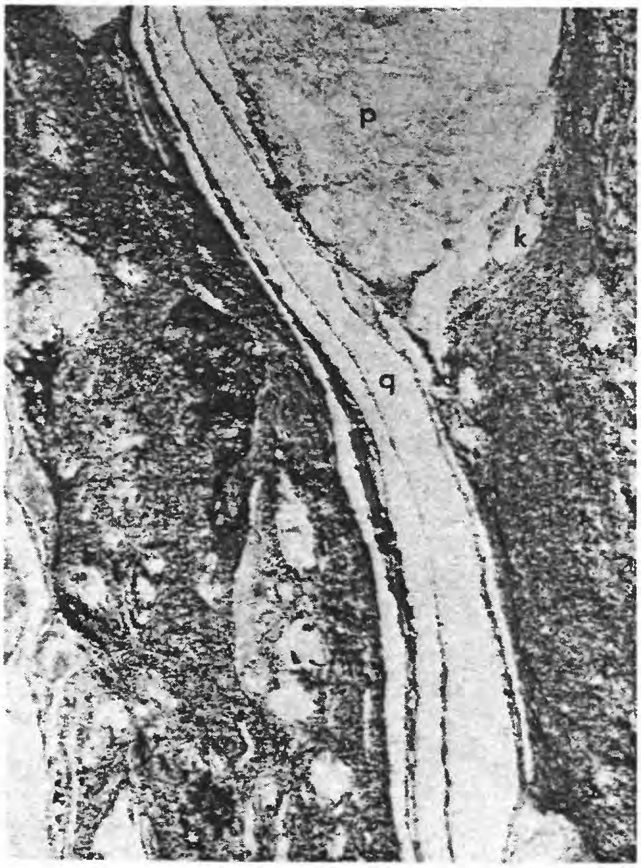
II-1.



II-2.

0 1 2 mm

II-3.



II-4.

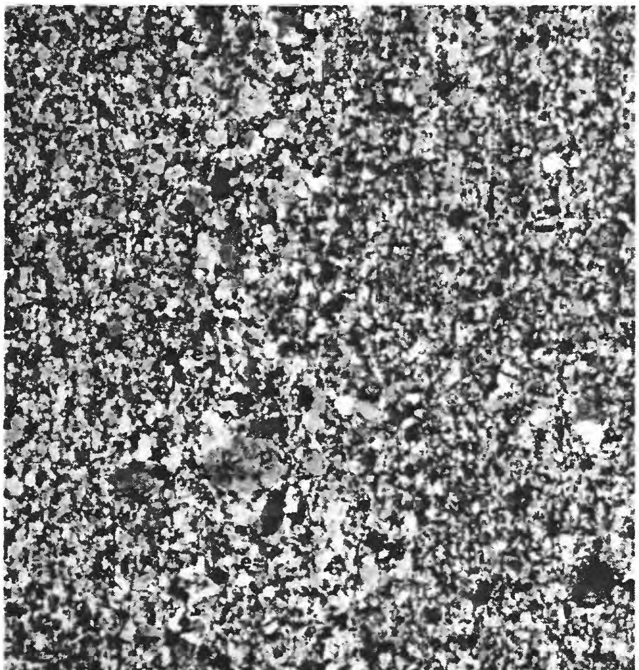
Plate 12.--Progressive cataclasis in the Hope Valley Alaskite Gneiss.

1. Noncataclastic alaskite gneiss from the Thompson quadrangle. The major minerals are quartz, plagioclase and microcline, with minor muscovite and a few flakes of biotite. Grains are essentially equigranular and have smooth boundaries; quartz is not sutured. The lenses of coarser-grained quartz are part of the quartz rods which typically occur in the Hope Valley Alaskite Gneiss. (T-2-88; T-20.0N; 11.0W).
2. Cataclastic alaskite gneiss. Small grains of microcline, plagioclase, and rarely quartz are in a very-fine-grained matrix of quartz and feldspar. The grains are variable in size and have irregular boundaries. Quartz is moderately sutured. (D2-285; D-29.0N; 0.1W).
3. Alaskite mylonite. Very-fine-grained quartz and feldspar with a few fine grains of microcline and plagioclase. Sample also contains very-fine-grained epidote, chlorite and sphene. The quartz grains are moderately sutured. The plagioclase grain in the center of the photo contains a core of microcline. (P2-248; P-24.7N; 5.5W).
4. Alaskite mylonite gneiss. Coarse microcline and plagioclase grains in a very-fine-grained matrix of quartz, feldspar and minor epidote and chlorite. The feldspar porphyroclasts are broken and the cracks are filled with very-fine-grained quartz and feldspar. (P2-320; P-23.0N; 7.3W; crossed nicols; magnification 20x; q - quartz; p - plagioclase; k - microcline; b - biotite; m - muscovite; e - epidote; qf - granulated quartz and feldspar.)

12-1.

0 1 2 mm

12-2.



12-3.

12-4.

Plate 13.--Mylonite and blastomylonite in the lower member of the Quinebaug Formation adjacent to the Lake Char fault plane.

1. Mylonitized hornblende gneiss. Partly recrystallized hornblende occurs as subhedral, twinned grains. The rest of the hornblende has ragged boundaries, contains abundant, minute opaque inclusions (grain in the upper left hand corner) and is partially neomineralized to epidote and biotite. Plagioclase grains are zoned and have irregular boundaries. The grain size is variable. (PN-65B; P-43.0N; 0.7W, sample was collected about 3 feet above the fault contact; crossed nicols.)
2. Same as 13-1 in plane light.
3. Hornblende-plagioclase mylonite. Uniformly very-fine-grained rock. Hornblende is recrystallized, and occurs as subhedral laths oriented parallel to the cataclastic lamination, which consists of hornblende rich and plagioclase rich laminae (photo is entirely of a hornblende rich lamina). Areas of plagioclase, such as the ones labelled, consist of clusters of very fine plagioclase grains. (PN-65A; P-43.0N; 0.7W, sample was collected 1 foot above the fault contact; plane light.)
4. Blastomylonite. Thoroughly neomineralized hornblende gneiss. Hornblende is chloritized and plagioclase is sericitized. Calcite and epidote are probably secondary from plagioclase and the sphene is secondary from hornblende. The calcite occurs mostly in small, discontinuous fractures. (P2-381; P-43.0N; 0.7W, sample was collected a few inches above

Plate 13.--Mylonite and blastomylonite in the lower member of the Quinebaug Formation adjacent to the Lake Char fault plane.--(continued)

4. (continued)

the fault contact; plane light.) (Magnification of each is 100x; p - plagioclase; h - hornblende; s - sphene; e - epidote; cl - chlorite; c - calcite; ps - sericitized plagioclase.)

13-1.

0 1 mm

13-2.

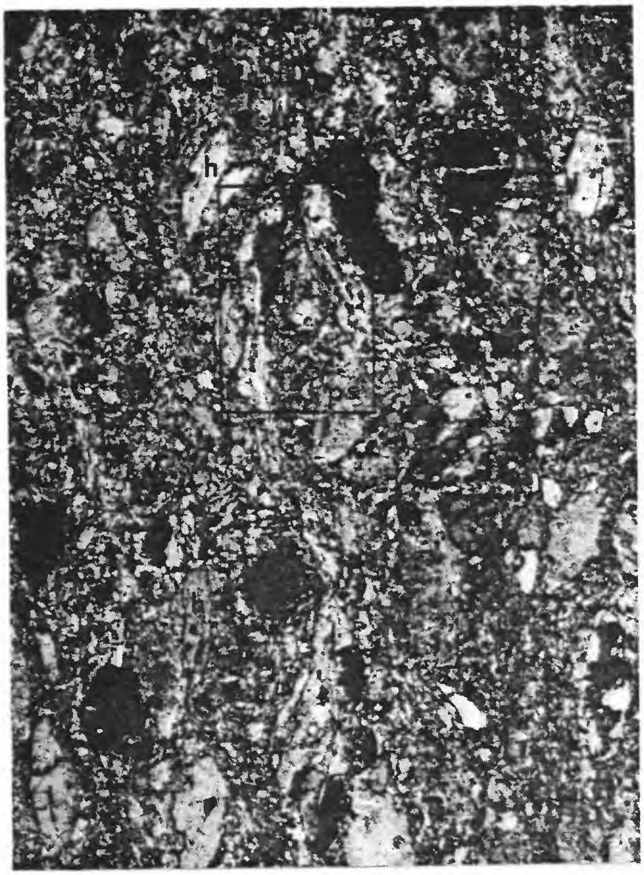
13-3.

13-4.

Plate 14.--Blastomylonitic hornblende gneiss of the lower member of Quinebaug Formation.

1. Blastomylonitic hornblende-plagioclase gneiss. Small-grained hornblende and plagioclase are in a very-fine-grained matrix of quartz, plagioclase, hornblende, epidote and chlorite. Hornblende is partially neomineralized to epidote and chlorite; plagioclase is partially neomineralized to sericite and epidote. (Crossed nicols; magnification 16x.)
2. Same as 14-1 in plane light.
3. Enlargement of the area outlined in the center of 14-1. Quartz in the matrix is strongly sutured, and is difficult to distinguish from the granulated plagioclase. Hornblende grains have ragged boundaries and show partial neomineralization to epidote along the boundaries. (Crossed nicols; magnification 65x.)
4. Same as 14-2 in plane light.

(P2-210; P-42.6N; 3.6W; h - hornblende; ps - sericitized plagioclase; q - quartz; p-q - granulated quartz and plagioclase; cl - chlorite; e - epidote.)



14-1.

14-2.

0 1 2 mm.

14-3.

14-4.

0 1 mm

Plate 15.--Cataclastic rocks of the Quinebaug Formation.

1. Plagioclase-quartz mylonite gneiss of the lower member of the Quinebaug Formation. Small-grained plagioclase and minor garnet are in a very-fine-grained matrix of quartz, plagioclase, biotite, epidote and sphene. Quartz in the matrix is moderately sutured. The plagioclase grains have rounded and irregular boundaries; the garnet is euhedral and not granulated. (Pl-164; P-22.6N; 17.7W; crossed nicols; magnification 16x.)
2. Same as 15-1 in plane light.
3. Cataclastic hornblende-plagioclase gneiss, of the upper member of the Quinebaug Formation. Cataclasis is along small fractures which cross the foliation of the rock. Along and between the fractures quartz and feldspar are ragged and the edges are chloritized. This is one of the few samples examined in which cataclasis is developing along fractures at an angle to the foliation rather than parallel to it. (Pl-141; P-37.6N; 22.8W; crossed nicols; magnification 20x.)
4. Plagioclase-hornblende mortar gneiss of the lower member of the Quinebaug Formation. Small to coarse hornblende and plagioclase grains have granulated boundaries. All quartz is uniformly fine grained and strongly sutured, except that which occurs as inclusions in the coarse hornblende grains. Hornblende is partially chloritized around the grain edges. (PN-4; P-19.5N; 15.8W; crossed nicols; magnification 24x.)

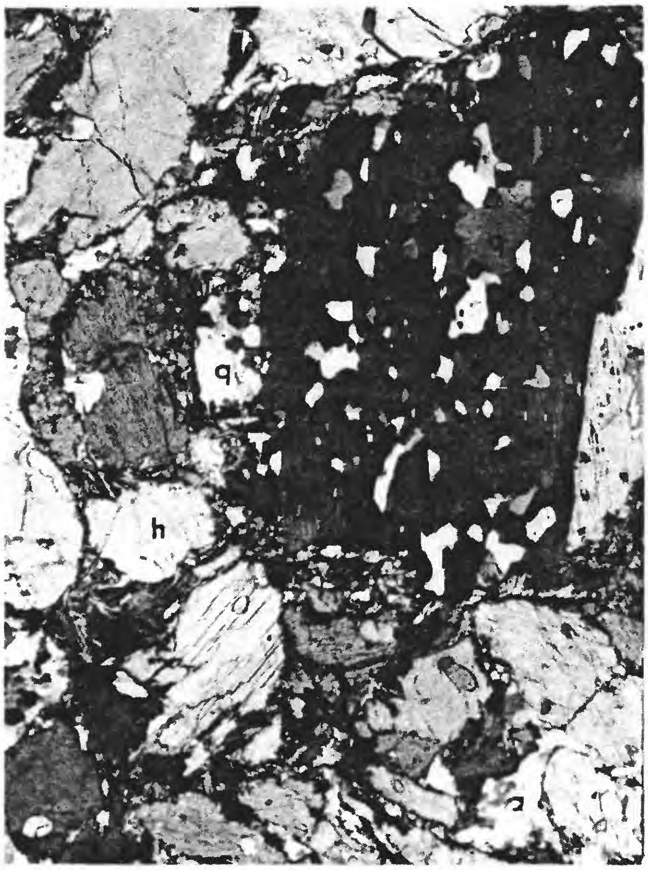
Plate 15.--Cataclastic rocks of the Quinebaug Formation.--(continued)

(q - quartz; p - plagioclase; qp - granulated quartz and plagioclase; qf - granulated quartz and feldspar; g - garnet; e - epidote; h - hornblende; cl - chlorite.)

15-1.

0 1 2 mm

15-2.



15-3.

0 1 mm

0 1 mm

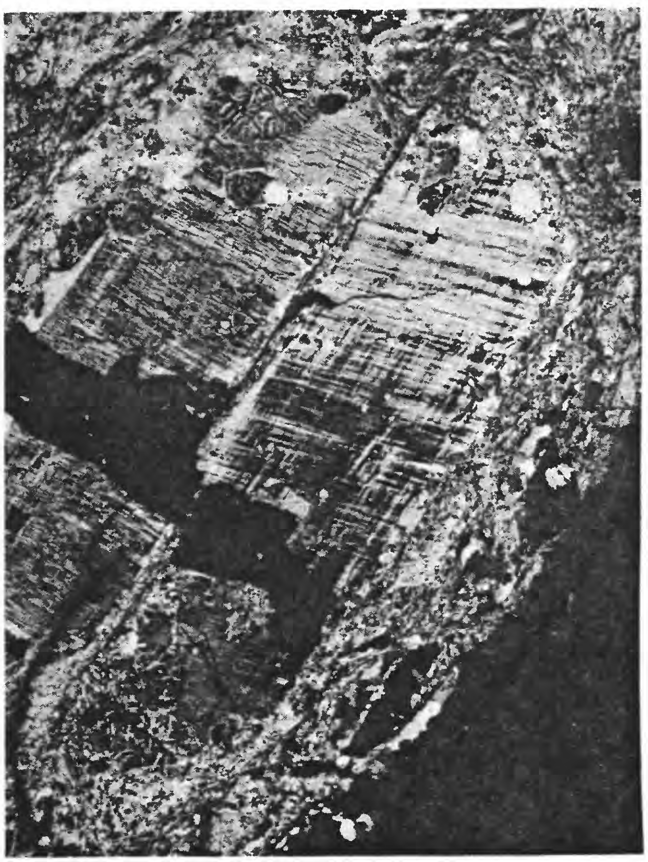
15-4.

Plate 16.--Porphyroclasts of microcline and plagioclase in the two feldspar mylonite gneiss of the lower member of the Quinebaug Formation.

1. Porphyroclast of microcline in a very-fine-grained matrix of quartz and feldspar. The microcline is fractured and the fractures are filled with quartz. (P2-264; P-23.5N; 7.5W; corssed nicols; magnification 40x.)
2. Porphyroclast of microcline in the lower left hand corner, containing wavy exsolution lamellae of plagioclase. The plagioclase in the lower right hand corner is myrmekitic. (Same sample as 16-1; crossed nicols; magnification 40x.)
3. Microcline porphyroclast in a very-fine-grained matrix of quartz, feldspar and chlorite. The fracture down the middle of the microcline grain is a Carlsbad twin plane along which the grain has fractured, and it is filled with very-fine-grained quartz and feldspar. Myrmekitic plagioclase occurs as inclusions in the microcline and along the edges of the grain. (PN-21C; P-21.6N; 9.8W; crossed nicols; magnification 15x.)
4. Microcline porphyroclast (upper right hand corner) and bent plagioclase porphyroclast (center) in a very-fine-grained matrix of quartz and feldspar. (Same sample as 16-1; crossed nicols; magnification 15x.)

16-1.

16-2.

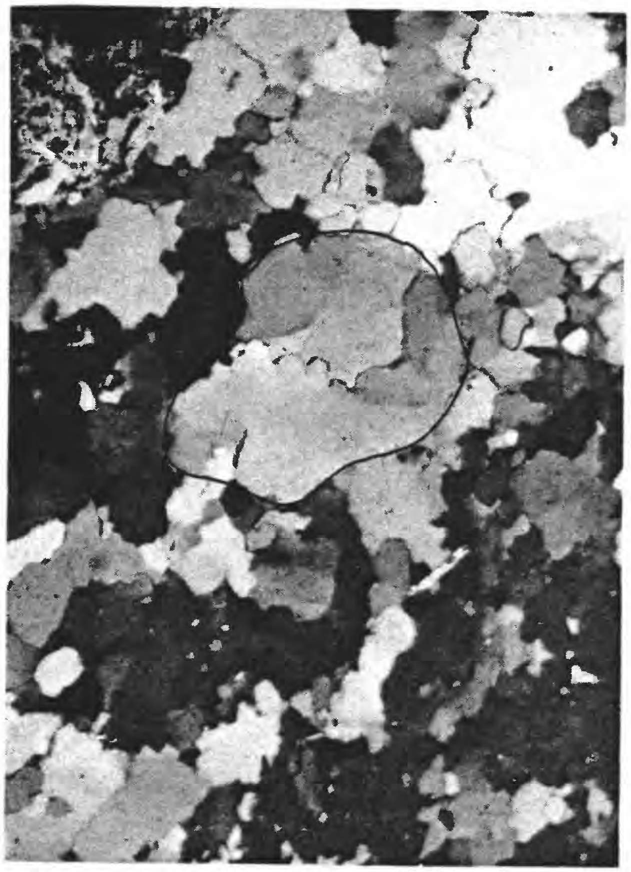


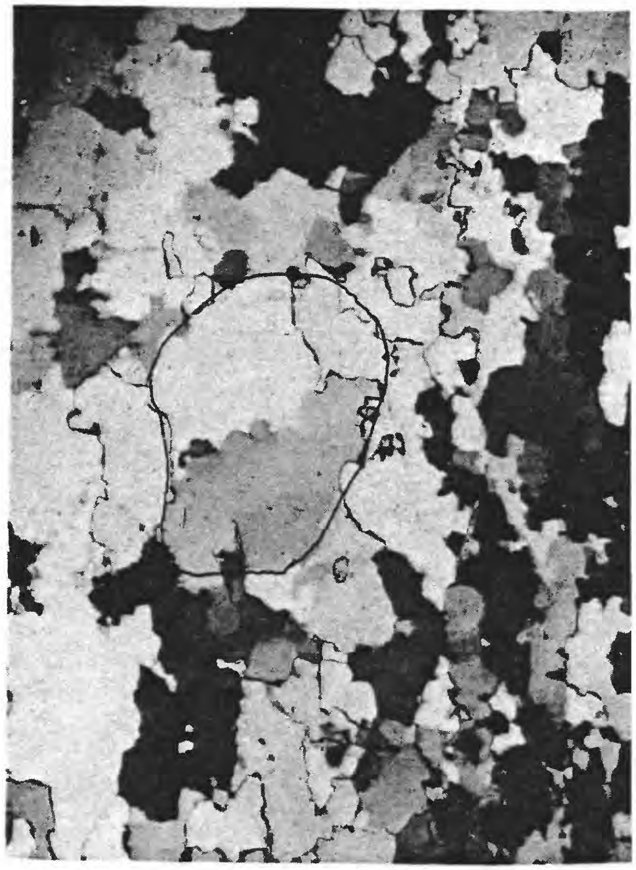
16-3.

16-4.

Plate 17.--Details of the fabric of some mylonites.

1. Suturing of quartz in mylonite of the garnet-biotite gneiss of the Tatnic Hill Formation. The area outlined was probably one quartz grain originally, and would have been about 0.5 mm diameter. It has recrystallized with strong suturing along the boundaries of the subunits of the grain which produce the undulose extinction. (P1-92; P-17.9N; 27.8W; crossed nicols, magnification 70x.)
2. Same as 17-1, with the section rotated about 45°.
3. Suturing of quartz in a quartz lamella of mylonitic mica-quartz schist of the Plainfield Formation. (D3-31; D-33.5N; 1.1W; crossed nicols; magnification 31x.)
4. Mylonitized actinolite quartzite of the Plainfield Formation. Very fine euhedra of actinolite are probably recrystallized. Quartz is very fine grained and sutured. (D5-14; D-29.8N; 0.3W; crossed nicols; magnification 100x; a - actinolite.)





17-1.

0 1 mm

17-2.

0 1 mm

0 0.5 mm 17-4.