BEDROCK GEOLOGIC MAP OF THE OLD MYSTIC AND PART OF THE MYSTIC QUADRANGLES, CONNECTICUT, NEW YORK AND RHODE ISLAND

By Richard Goldsmith

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INTRODUCTION

Most of the bedrock of the Mystic and Old Mystic quadrangles is part of an upper Proterozoic gneissic, crystalline terrane extending from eastern Massachusetts through western Rhode Island to and across southeastern Connecticut north of Long Island Sound. This terrane, equated with the Avalonian terrane of Newfoundland (Rast and others, 1976; Skehan and Murray, 1980), is separated from a block of metamorphosed volcanic and sedimentary rocks of Ordovician or older age, the Quinebaug and Tatnic Hill Formations, by the ductile, north- and west-dipping Honey Hill–Lake Char fault system which crosses the northern part of the Old Mystic quadrangle (figs. 1 and 2). The crystalline terrane, in the lower plate, consists predominantly of granitoid gneisses, the Sterling Plutonic Group of Late Proterozoic age (Day and others, 1980; Goldsmith, 1980), that intrude and are interleaved with a layered sequence consisting of the predominantly metaclastic Plainfield Formation below and the primarily metavolcanic and metaplutonic Waterford Group above. Regional metamorphism probably took place in the early Paleozoic and possibly in the Proterozoic, but metamorphic events continued, at least in the upper plate, during the middle Paleozoic. In the Silurian, the laccolithic Preston Gabbro was intruded in the developing Honey Hill fault zone. During the middle and into the late Paleozoic, deformation continued both along the Honey Hill fault zone and in the gneissic terrane, where it produced a major foliation arch and a complex interference pattern.

Late in the Paleozoic, late- to post-tectonic granite and quartz monzonite, including the Westerly and Narragansett Pier Granites, were intruded in the coastal area of Rhode Island and Connecticut. During the Mesozoic, brittle faulting accompanied by hydrothermal activity occurred in a north-south zone from Mystic River through the Preston Gabbro area. The prominent silexite mass at Lantern Hill formed at this time.

The bedrock in the map area is partly covered by glacial deposits of Pleistocene age (Gaffney, 1966; Upson, 1971). Accordingly, bedrock exposures are discontinuous and irregularly distributed. South of the mainland, Fishers Island, Wicopesett Island (not shown on this map), Napatree Point, and Sandy Point are composed of thick unconsolidated glacial deposits, and no bedrock information could be obtained.

ROCKS OF THE LOWER PLATE

Stratified Rocks

Plainfield Formation

The Plainfield Formation in the New London area was divided into three parts (Goldsmith, 1976) on the basis of mapping in the Thames River area to the west: (1) an upper partly calcareous quartzitic-pelitic section, (2) a middle, largely quartzo-feldspathic and calcareous section, and (3) a lower quartzitic and pelitic section. In the Old Mystic and Mystic quadrangles, only the upper and middle parts are represented. Thick beds of quartzite and pelitic schist and gneiss and sillimanitic quartzite typical of what was called the lower Plainfield in the Uncasville and Montville quadrangles (to the west) are not observed in the Old Mystic and Mystic quadrangles. This is attributed to the general eastward plunge of the structure off the Montville dome (fig. 2). The boundary of the Plainfield Formation with the overlying Mamacoke Formation is drawn at the top of the uppermost thick section of quartzite. The section exposed in the northeast corner of the map near Wyassup Lake is continuous from primarily metavolcanic rocks (Zh, Za) into a transitional zone of mixed metavolcanic and metaclastic rocks (Zmhq) within which is gray biotite-plagioclase gneiss (Zmb). These rocks pass downward concordantly into a sequence of gray biotitic quartzite, slightly calcareous quartzite, and quartz-biotite pelite assigned to the Plainfield Formation (Zp). The latter rocks are typical of rocks mapped as the upper part of the Plainfield in the New London area. Quartzite adjacent to the Mamacoke Formation usually contains thin layers of quartz-bearing amphibolite. In the Mystic quadrangle, this can be seen in the undivided Plainfield Formation (Zp) in the Bindloss Brook area, and in the Old Mystic quadrangle, in the undivided Plainfield Formation (Zp) in the Bindloss Brook area and at North Stonington, and in quartzite (Zpq) on the north side of Wyassup Lake. The Plainfield Formation in the southern part of the area contains fewer metavolcanic rocks and more quartzitic rocks than to the north, and it is possible that the boundary of the Plainfield with the Mamacoke Formation has been drawn higher in the section in the south. Part of the Plainfield may be stratigraphically equivalent to the hornblende gneiss and quartzite (Zmhq) of the northern part of the area. Amphibolite in the Plainfield section south of Wyassup Lake and at Pitcher Mountain (Zpa) is interpreted as lenses of mafic volcanics in the section rather than tectonic slices or infolds of rock normally higher in the section.

Calc-silicate quartzite and gneiss (Zpc) form a distinctive unit that, in the Uncasville quadrangle, was considered to lie near the base of the middle part of the Plainfield. The calc-silicate quartzite could be interpreted as equivalent stratigraphically to less coarsely recrystallized calcareous quartzites in the upper part of the Plainfield in the northern belt. However, as mapped, it appears to be down in the section. It is noteworthy that this rock in most places lies adjacent to or in granite gneiss throughout most of the New London area. The significance of this is not apparent.

Waterford Group

The distinctive formations recognized in the quadrangles to the west that have been assigned to the Waterford Group (Goldsmith, 1980) are not recognized as such in the Old Mystic and Mystic quadrangles, except for the gray biotite-plagioclase gneiss of the Mamacoke Formation (Zmb). The more mafic parts of the Waterford Group in the Old Mystic quadrangle, as exposed east and west of the Preston Gabbro, are probably equivalent stratigraphically to parts of the New London Gneiss and Rope Ferry Gneiss (previously called Monson Gneiss) of the Niantic-New London areas (Goldsmith, 1967 c,d). The hornblende-biotite gneiss (Zh, sample 19 of table 1,) resembles Rope Ferry Gneiss in composition. In the northern Old Mystic quadrangle, volcanic and volcaniclastic rocks are more abundant and plutonic rocks are less abundant than in the New London-Mystic belt of metavolcanic and metaplutonic rocks. The partly quartzitic unit (Zmhq) could be equivalent to the upper part of the Mamacoke in the Niantic-New London area, but if so distinctive layers, such as a light-colored rock containing quartz-sillimanite ellipsoids, a blocky amphibolite, and a garnet-rich biotite sillimanite rock, seem to be missing. However, facies could have changed between the two areas, particularly if as expected in a palinspastic reconstruction, the two areas were originally far apart.

The bulk of the Mamacoke Formation in the Mystic and Old Mystic quadrangles is an indistinctly layered (hornblende)-biotite-quartz-plagioclase gneiss (tables 1 and 2) with a few dark layers of amphibolite and light-colored layers of alaskite and biotite granite gneiss. The interlayering with alaskite is suggestive of a sequence of layered intermediate and felsic volcanic rocks. Good exposures of this sort of layering can be seen in ledges northwest of Wyassup Lake, on the south slopes of Swantown Hill, and on Conn. Rte 184 west of Old Mystic.

Some biotite gneiss of the Mamacoke is difficult to distinguish in the field from phases of the Potter Hill Granite Gneiss (compare samples 17 and 13, of table 1, and sample 4 of table 2). The boundary between biotite gneiss (Zmb) of the Mamacoke Formation and the adjacent Potter Hill is indistinct in the Copps Brook area north of Pequot Trail and in the faulted area west of Whitford Pond. The biotite gneiss in the Lee Brook area was mapped as fine to medium-grained granite gneiss in the adjacent Uncasville quadrangle. Possibly the biotite gneiss is an earlier, potassium-poor phase of the Potter Hill, or conversely the Potter Hill is potash-feldspar enriched, mobilized biotite gneiss. Indeed, Foye (1949, p. 61) considered the Mamacoke a phase of the "Sterling orthogneiss" and derived from "Monson orthogneiss" by infiltration of "Sterling batholithic solutions." If the biotite gneiss of the Mamacoke is a metaplutonic rock rather than a metavolcanic rock, its stratigraphic position is not reliable, and its use in interpreting the structure of the area is limited.

The biotite gneiss of the Mamacoke (Zmb) becomes increasingly less layered, more coarsely crystalline and more granitoid southward in the Mystic quadrangle, giving the appearance of having been melted and homogenized. It passes into a relatively homogeneous hornblende-biotite gneiss of granodioritic composition (Zmhb, samples 5 and 6 of table 2). Because of its fairly uniform mineral composition, the granodioritic gneiss (Zmhb) may have been an intrusive phase in the volcanic pile before metamorphism. Both phases of the Mamacoke Formation were mapped by Moore (1967) in the Watch Hill quadrangle to the east as "metavolcanic rocks." I have mapped the Mamacoke Formation in the Old Mystic and Mystic quadrangles as a metavolcanic unit.

The hornblende gneiss and amphibolite (Zha) in the southeastern corner of the Old Mystic quadrangle and near North Stonington is considered to be a more highly recrystallized and deformed equivalent of the hornblende gneiss and the amphibolite (Zh and Za) in the Preston Gabbro area (north-central part of map). It does, however, contain some rock types, including a rusty semipelitic gneiss not recognized in the latter area. It also lacks the ubiquitous alaskitic layers of the northern units that serve to distinguish the rocks of the Waterford Group from those of the Quinebaug Formation.

Plutonic Rocks

Sterling Plutonic Group

The Hope Valley Alaskite Gneiss (Zhv) forms thick to thin sheets intercalated with the other rocks of the basement complex. Large sheets are clearly intrusive into the Plainfield Formation, but small layers are less clearly intrusive. In the northwest belt near the Honey Hill fault zone, the Hope Valley on the whole is finer grained than elsewhere and appears to be melded into the adjacent layers through cataclasis and recrystallization (ductile flow). The Hope Valley contains less biotite and is less calcic where it is adjacent to quartzite of the Plainfield (sample 9 of table 1) than where it forms layers in the more biotitic Mamacoke Formation (sample 8 of table 1). The white, fine-grained Hope Valley (Zhvf) is not greatly different mineralogically from normal Hope Valley, but has a more sugary aspect in outcrop and is slightly more plagioclase-rich. Slight differences in composition of the Hope Valley could be attributable to contamination by the different host rocks that it intrudes.

It is possible that the thin alaskitic layers in the Waterford Group are extrusive equivalents of the intrusive sheets in the Plainfield Formation. Possibly some or all of the Hope Valley represents extrusive sheets that have been remobilized. The Potter Hill Granite Gneiss (Feininger, 1965) is the most extensive single rock type in the quadrangle. The Potter Hill on Gallup Hill is the rock mapped in the Uncasville and Montville quadrangles to the west as biotite granite gneiss (Goldsmith, 1976a,b) The more coarsely-grained augen granite gneiss (Zpha) between Yawbucs Brook and Ryder Road (northeast part of map) was mapped as a unit separate from the Potter Hill. However, except for the porphyritic aspect, the rocks are not dissimilar in composition and texture, and phases similar to the augen gneiss crop out in a few small areas within the Potter Hill. A similar mass was mapped as inequigranular gneiss near Gales Ferry in the adjacent Uncasville quadrangle (Goldsmith, 1967a).

Permian Granites

The Permian granites are characterized by intrusive habit, igneous textures, lack of metamorphism, and chemically by the relative abundance of rare earth elements, modally expressed by allanite (table 1). The lenses of Narragansett Pier Granite (Pnp) in the Old Mystic quadrangle are west of a larger mass exposed in the type area of Westerly, Rhode Island. In the Old Mystic quadrangle, the Narragansett Pier tends to have been emplaced paraconcordantly to the trends of the folliation in the host rocks; however, in a few places, the granite is clearly discordant. The dikes of Westerly Granite are everywhere clearly discordant and are considered to be slightly younger than the Narragansett Pier Granite as it is in the type area (Quinn, 1971).

The porphyritic quartz monzonite (Pqm) is a unique rock that has not been previously reported in the region. Its consanguinity to the Narragansett Pier Granite is not only suggested by the chemistry and habit, but also because biotite-poor phases approach the Narragansett Pier in texture. This is most clearly seen in the small masses west of Long Pond.

ROCKS OF THE UPPER PLATE

Stratified rocks

Quinebaug and Tatnic Hill Formations

The Quinebaug Formation in the Old Mystic quadrangle is not divided into the subdivisions established by Dixon in the Plainfield and Danielson quadrangles to the north (Dixon, 1965, 1968) because the Quinebaug is disrupted by intrusion of gabbro and by faulting. Although the Quinebaug contains rock types similar to those in the upper Waterford Group, the two can be distinguished fairly readily by the common thinner layering, more diverse composition, and lack of alaskitic layers in the Quinebaug.

Only the lower part of the Tatnic Hill Formation (OZt) is present in the northwest corner of the map, and it appears to be conformable with the Quinebaug Formation here because the two appear to be intercalated in the contact zone. However, to the north in the Jewett City quadrangle, units of the Quinebaug are missing along the contact, and the contact is interpreted to be a fault (Dixon, 1983).

The Tatnic Hill and Quinebaug Formations are considered to be either Ordovician or Late Proterozoic in age on the basis of regional correlations and isotopic age determinations (Goldsmith and others, 1982). The possibility that they are no younger than Cambrian (Goldsmith, 1980, p. A100) is discounted.

Intrusive Rocks

Preston Gabbro

The Preston Gabbro and related phases in the Old Mystic quadrangle are satellitic to a much larger mass to the north in the Jewett City quadrangle. The poorly exposed diorite (Spd) at the quadrangle boundary west of Cossuduck Road is the southern tail of the main mass. The Preston Gabbro has been studied by Loughlin (1912), Sclar (1958), and more recently mapped by Dixon (written commun., 1976, 1968). Sclar considered the gabbro to be a west-dipping laccolith. Magnetic and gravity data support this interpretation. Griscom and Bromery, (1968, p. 426) indicate that the general form of the pluton is a nearly circular basin-like mass, now tilted down to the west. In the Old Mystic quadrangle, the gabbro masses most likely represent separate intrusions related to the upper part of the main mass althouth they may be, in part, faulted blocks of the upper part of the main mass. Sclar described the bulk of the gabbro as an ophitic to subophitic clinopyroxene gabbro and quartz clinopyroxene gabbro. Dixon (1978) describes the interior of the gabbro as olivine - two-pyroxene gabbro and the upper part as a quartz-hornblende diorite. Most of the rock in the Old Mystic quadrangle however, is hornblende gabbro containing only relic pyroxene (table 1). The igneous texture is well preserved where not transformed by shearing. Chemically, the phases of the gabbro form a consanguinous series (Goldsmith, unpublished data). The late granodioritic phase, in places trondhjemitic, is at the top of the main mass in the Jewett City quadrangle to the north (Dixon, 1978) and dikes of trondhjemite are numerous near the east edge. A trondhjemite dike cutting diorite in the Jewett City quadrangle has been dated by R. E. Zartman, measuring Pb-U isotopes in zircon, at about 423 m.y. (R. E. Zartman, written commun., 1979). The gabbro is clearly intrusive into the previously metamorphosed Quinebaug Formation. Where gabbro becomes sheared in the Honey Hill fault zone, coarse-grained hornblende is recrystallized to fine-grained hornblende forming amphibolite that is not readily distinguishable from amphibolite of the Waterford Group or Quinebaug Formation.

METAMORPHISM

The entire map area is within the sillimanite-muscovite zone of metamorphism except in the northwest corner of the Old Mystic quadrangle where the Tatnic Hill Formation and part of the Quinebaug Formation are in the sillimanite-potassium feldspar zone of metamorphism. Diagnostic minerals for grade of metamorphism in the rocks of the lower plate are mainly in the Plainfield Formation. Sillimanite is the principle index mineral. Calc-silicate quartz schist contains diopside and bytownite near Burnetts Corner, and some calc-quartzites contain clino-pyroxene and labradorite in several places. All the rocks older than the Preston Gabbro have undergone pervasive regional dynamothermal metamorphism. Pervasive deformation of the rocks below the Honey Hill fault has occurred at elevated temperatures, and two main phases of deformation and recrystallization are indicated: one forming the primary foliation and the other folding this foliation and, in places, forming a second foliation which seems to have obliterated the first in zones of strong shear.

Retrogressive metamorphism has occurred only along the fault systems. Deformation along the Honey Hill fault zone was essentially at dry amphibolite-facies conditions. The primary effect of this deformation was in reducing the grain size of the rocks by comminution of the consistuent minerals. Only where the Lantern Hill fault system is superimposed on the Honey Hill zone is there extensive and pervasive development of chlorite, epidote, and secondary muscovite. Mica from a slickensided fault surface at Lantern Hill was shown by x-ray analysis to be a mixed layer illite-muscovite.

STRUCTURE

The distribution of units in the map area indicates a complex fold and fault interference pattern. Major structural features are a central, doubly-plunging foliation arch, the Potter Hill dome; a paraquaquaversal basin, the Mystic basin; a complexly folded and sheared zone on the south limb of the antiform, the Mystic node; a refolded secondary antiform, the Mystic antiform, the Honey Hill ductile fault zone; and the Lantern Hill brittle fault system. Relation of the structures in the Mystic and Old Mystic quadrangles to the surrounding region is indicated in figure 2.

The gneisses, schists, and quartzites of the basement complex have a primary foliation (S_1) which is metamorphic in the stratified rocks and a metamorphic foliation or syntectonic flow-foliation in the plutonic rocks. This foliation is apparently related to regionally developed isoclinal folds now with inclined to recumbent axial surfaces (F_1). The foliation has been refolded pervasively by flexural flow-folds (F_2) forming a foliation arch with moderately to steeply inclined axial surfaces (S_2). Continued or later folding (F_{3+}) with upright axial surfaces produced the present configuration. Mesoscopic isoclinal folds (F_1) in which primary foliation is axial planar to folded layering are rare, and these, indicated by combined isoclinal fold symbol and foliation symbol, were seen primarily in the northern belts of the Waterford Group and Plainfield Formation, as in the quartzite along Yawbucs Brook southwest of Wyassup Lake. The predominant folding in the quadrangle (F_2) involves both foliation and layering in the stratified rocks and gneissosity in the older plutonic rocks, and is related to development of the major foliation arch. In many places, particularly in the southern part of the area, two generations of foliation (S_1 and S_2) can be discerned in an outcrop.

The presence of early recumbent isoclinal folds (F_1) is based on an interpretation of the regional stratigraphy and minor structures and on map pattern (Dixon and Lundgren, 1968). The Potter Hill dome is apparently superposed on an early anticline which is the eastward extension of the Montville dome (Goldsmith, 1967b) and Selden Neck dome (Lundgren, 1963). The width of the outcrop area of the Mamacoke Formation in the Mystic quadrangle is interpreted as resulting from a thickening on the crest of an early recumbent fold, an extension of the refolded Hunts Brook syncline (Goldsmith, 1961). Mesoscopic tight isoclinal folding of the Plainfield seen in many exposures suggests that this formation is isoclinally folded. Megascopically, the pattern of mapped quartzite across Cossaduck Hill to North Stonington also suggests this if the sills of Hope Valley Alaskite Gneiss are disregarded. However, such folds are speculative and are not shown on map or cross sections.

The dominant F_2 folds are readily apparent. The south-verging Potter Hill foliation arch brings up in its core the Potter Hill Granite Gneiss. On its northern flank is an antiform - synform set that is also anticlinal and synclinal. The configuration of folds on the steep south flank of the arch is more complex. The arch is best illustrated in section *D–D"* and *E–E'*. The complication of the Mystic basin and the complicated folds of the Mystic node are illustrated in sections *A–A"*, *B–B'*, *C–C'*.

Development of the Potter Hill foliation arch occurred at a time when temperatures were high and the rocks responded plastically. The plastic behavior is more evident to the south than to the north where the arrangement of formations is planar rather than disharmonic. Flexural flow-folds (F_2) on the northern limb of the foliation arch show a rotation sense mostly north over south, but locally in the opposite sense. Minor folds plunge to northwest to the west and northerly to the east although plunges of recognizable first generation folds (F_1) are variable. Minor folds (F_2) on the crest and southern limb plunge in a more pronounced east-west direction. In the southern limb, the axial surfaces of minor folds are inclined steeply both to north and south. Drag sense is predominantly up from the south. This is well illustrated in the zone from Wheeler Brook and Merritt Hill south into the Mystic quadrangle. The steeply-dipping south flank of the arch is characterized by tight folding west of the Mystic River and in the Taugwank synform. Plunges of folds in this area are quite variable and locally steep. Folded fold axes are common.

The Mystic node is a complex zone of tight folding and shearing. It would appear that the Mamacoke Formation south of the Mystic basin is backfolded and that the Plainfield Formation in the Bindloss Brook area is inverted. The Plainfield here is interpreted as occupying an F_1 anticlinal hinge as is the narrow belt of Plainfield Formation in the Pequot Trail area. The zone in the Bindloss Brook area appears to terminate southward along an annealed northeast to east-west trending shear.

The Mystic antiform is south-verging like the Potter Hill antiform and bears a similar pattern of minor drag folds. Axial surfaces of small folds in foliation and layering dip predominantly to the north, but flatten toward the crest of the antiform and dip more gently than the overall dip of the long limbs of the folds south of the crest. This is most clearly seen in the area around Silvias Pond. In places, a second foliation marked by orientation of biotite flakes has developed parallel to the axial surfaces of the minor drag folds.

The Mystic antiform has been folded near Stonington by a northeast-trending fold which as folded the crest and steep limb of the older antiform. The fold at Stonington may reflect drag along a major northeast-trending fault or shear zone, having right lateral offset that lies in the adjacent Ashaway and Watch Hill quadrangles to the east (Feininger, 1965; Moore, 1967; Smith and Barosh, 1980).

A fold with similar style, but with opposite sense is located in the Noank area. This fold may actually be superimposed on a tightly appressed synform complementary to the Mystic antiform. An antiformal area between the Stonington and Noank folds may be present in the Mason Island-Quiambog Cove sector. Minor folds related to this phase of folding are evident primarily in the coastal area. The abrupt spooning of the Noank fold suggests a later northwest-trending antiform offshore to the southeast. The Mystic basin is an obvious product of superimposed folding.

Zones of shear are prominent in the map area. Overturned limbs of minor folds of the F_2 generation have been sheared off, but it is not clear that this is true for the major folds. These zones of shear show no cataclasis and such shears are recognized by abrupt changes in trend of foliation along a narrow zone, usually with some evidence of drag, and in places by abrupt juxtaposition of rock units across the zone. The shear in the Bindloss Brook area and the shear in the Copps Brook area east of Quoketaug Hill and north of the Pequot Trail are good examples of such features. This shear may curve southward to become the north side of the Mamacoke-Plainfield contact along Pequot Trail as interpreted, or it may somehow pass southwestward to join the shear south of Bindloss Brook in the northwest Mystic quadrangle. The Copps Brook shear projects eastward in a zone of vertical foliation in the south limb of the Potter Hill antiform. It or another shear concealed in the foliation to the south may project eastward south of Merrit Hill into the Ashaway quadrangle to become the discordance shown by Feininger (1965) extending from Ashaway east-southeastward along the Pawcatuck River. However, the Copps Brook shear is interpreted as connecting near Harvey Road with a inferred shear southeast of Long Pond, clearly expressed in the foliation pattern in the Potter Hill Granite Gneiss. A shear is interpreted between the Mamacoke and Plainfield Formations south of the Haleys Brook; to the east it swings northerly an undetermined distance around the east side of the Mystic basin. A shear could be interpreted along the north side of the Mamacoke Formation in the Long Pond belt to accommodate discordancies and missing section east and west of the quadrangles (fig. 2). For lack of conclusive evidence, however, a shear at this locality has not been shown on this map.

Plunges of minor folds and trends of foliation indicate that both horizontal and vertical components of movement have been involved in and along the zones of shear. Steep plunges are abundant in the east-plunging Taugwank synform north of Pequot Trail. The pattern of deformation southeast and south of the Mystic basin clearly involves folding of a disharmonic nature coupled with plastic deformation and movement of folded semi-coherent blocks against one another along fairly discrete movement planes. As no cataclasis is evident, deformation apparently took place at high temperature as a flowage phenomenon.

Places in which the gneissic foliation has been folded by drag along the locus of non-foliated seams of granite several millimeters in width and as much as several meters long are relatively abundant in the gneisses of the coastal area. The seams have a predominant northwest trend, but neither horizontal nor vertical displacement seems to be consistent over the area. The seams are observed only in outcrop and in places form conjugate sets bounding edges of blocks of rock that have moved slightly with respect to each other. The seams must have formed at a time when the rocks were at or near temperatures at which partial melting could take place. They deform folded foliation but are cut sharply by aplite and pegmatite dikes related to the Narragansett Pier and Westerly Granites.

Honey Hill Fault

Minor structural features on either side of the Honey Hill fault are clearly discordant as is most clearly seen on the northwest corner of the map. Rock units above the fault zone are broken into slices and blocks whereas units below the fault zone have a marked parallelism. Within the fault zone, units are lenticular and truncated at low angles. Major foliation trends south of the fault roughly parallel the fault and are continuous northward into the fault zone. Also, the grain size of the rocks becomes finer towards the fault zone although not everywhere consistently, until eventually layers of laminated blasto-mylonite and mylonite are reached. This is a strong indication that the deformation along the Honey Hill fault was distributive and produced by the same stress field that controlled the foliation pattern in the rocks of the lower plate. Presumably in this case, the deformation would coincide with the development of the foliation arch (F_2). However, foliation is variably folded in partly cataclastic rock units near the Honey Hill fault zone and the inference is that this foliation is F_1 and that the folding and movement along the fault was F_2 and was in part metamorphic and continued after or late in the development of the foliation arch (F_2) to the south. Several investigators have observed that the Honey Hill fault has had a long history (Lundgren and Ebblin, 1972; Sclar, 1958; Wintsch, 1979; Dixon, 1978).

Axial planes of minor folds in the area of the northeast-trending segment of the Honey Hill fault zone, as northeast of Ashwillet Brook, tend to be oriented in a northwesterly direction. Here axial planes are fairly gently-dipping and axes plunging northward. Movement sense is northeast over southwest. Further southeast toward Wyassup Lake, normal northeast orientation is prevalent. Two sets of folds of foliation are evident in places, the northwest set later than the northeast set. This northwest orientation is approximately axial planar to the great right-angled bend in the regional trend around the Preston Gabbro and may be related to this flexure. In many places, and east-over-west rotation is indicated in minor folds in the mylonite zone. This led Lundgren and Ebblin (1972) to postulate that the Honey Hill fault represented a zone along which the cover rocks (Quinebaug and Tatnic Hill Formations) slid westward off the rising basement complex to the east and south. This may indeed have occurred, but is considered to be a late stage of movement. Vergence in the foliation arch is to the south and east.

Lantern Hill Fault

The Lantern Hill fault system is a zone of north-south trending brittle fracture accompanied by silicification and hydrothermal alteration. Branches of the fault cut through the Preston Gabbro, but the main trace is shifted to the northeast following the Honey Hill Fault zone so that the fault becomes the north-trending normal fault east of the gabbro shown by Dixon (1965, written commun., 1979) paralleling the north-trending ductile Lake Char fault. The Preston Gabbro presumably acted as a resistant knot and the Honey Hill-Lake Char system offered an easier locus for fracture. Mylonitic rocks are clearly cut by and altered along the Lantern Hill fault system. The faults in Phelps Brook west of Cossaduck Hill are based on apparent offsets of units and by the presence of outcrops of brecciated rock along the valley walls, most noticeably in ledges of Hope Valley Alaskite Gneiss. The faults cutting the Indiantown Road ridge north of Iron Street were similarly determined. Vein quartz and slickensides flank the Lantern Hill fault in the Mystic River, along Whitford Brook, and along the fault in the Mystic Reservoir.

Displacement along the fault system increases from south to north. Control for the amount of movement is poor in the Mystic River area, but appears to be about 100 m of stratigraphic throw. Stratigraphic throw using the top of the Wintechog Hill belt of alaskite gneiss across Lantern Hill is about 420 m, but measured from the east of the eastermost fault cutting Wintechog Hill is only about 250 m. The sense of movement on the fault system east of Lantern Hill suggests that a partial graben having blocks dropping down towards Lantern Hill, but having marked uplift east of Lantern Hill. The quartz mass appears to have been deposited in a strain shadow or zone of tension south of the resistant gabbro. A complex down-dropped block athwart the main trend of the Lantern Hill fault is evident south and southwest of Prentice Mountain (north-central). The silicified rock north of Ayer Hill is probably part of the Lantern Hill system where it is dispersed through the gabbro.

The Lantern Hill fault is post-Permian in age as it is younger than the Narragansett Pier and Westerly Granites. It is probably Triassic or Jurassic in age based on analogy to other silicified north-trending faults in New England (Rodgers, 1970, p. 107, 111). Aleinikoff (1978) has dated a lamprophyre dike cutting a silicified zone in southern New Hampshire as Jurassic in age.

Joints

The predominant trend of joints is north-south, but joints to northeast and northwest trend strike are present locally. The main joint trend and the variations in the trend can be readily determined by looking at the topography as expressed on the map.

GEOLOGIC HISTORY

Regional metamorphism of the gneissic basement and the allochthonous cover rocks north of the Honey Hill fault probably occurred in the early Paleozoic (Zartman and others, 1965; Pignolet and others, 1980). However, there is considerable evidence, both inferential and from isotopic dating, that an episode or episodes of middle Paleozoic metamorphisms affected the rocks of the upper plate at least (Pignolet and others, 1980) and involved the Honey Hill fault zone and perforce the Preston Gabbro. The Preston Gabbro has been deformed and partly recrystallized in the zone of ductile deformation along the Honey Hill fault zone, but is clearly younger than the regional metamorphism of the surrounding rocks. According to Dixon (1978), the gabbro contains inclusions of mylonite.

The plastic deformation during development of the foliation arch calls for temperatures near minimum melting conditions. Regional heating during the late Paleozoic (see Lundgren, 1966) prior to and during emplacement of the Narragansett Pier Granite could approach these conditions. The plastic nature of the deformation (F_2) is increasingly obvious to the south, which is apparently the direction of increased temperatures. The coastal area of Rhode Island and Connecticut is also the zone of emplacement of the Permian granites. Cooling must have been rapid, however, for dikes of Westerly Granite cut all earlier metamorphic fabrics.

The development of the foliation arch (F_2) occurred prior to the emplacement of the Permian-Westerly Granite. The emplacement of the Narragansett Pier Granite may not have been much later than the development of the foliation arch. The semi-concordant nature of masses of this rock suggest structural control for their emplacement at the time when temperatures were somewhat elevated. In the Uncasville quadrangle to the west, undeformed pegmatite of a type related to the Narragansett Pier Granite cuts blastomylonitic alaskite gneiss giving a minimum age for ductile faulting along the Honey Hill fault.

Using the above observations, the following history can be reconstructed:

1) Late Proterozoic—Deposition of the Plainfield Formation and the overlying Waterford Group in a developing volcanic environment. Intrusion of associated hypabyssal and plutonic rocks. Possible deposition elsewhere of Quinebaug and Tatnic Hill Formations.

2) Ordovician—Deposition of the Quineburg and Tatnic Hill Formations in a developing trench west of the map area followed by regional metamorphism including deformation of the trench and margins leading to development of nappe structures and movement of Putnam block into juxtaposition with the Waterford–Sterling block along the Honey Hill fault zone.

3) Silurian throuth Carboniferous—Emplacement of Preston Gabbro as a sheet into the Honey Hill fault zone. Continued movement of the Honey Hill fault zone and deformation of the Preston Gabbro, and development of foliation arch at at time when isotherms were higher to the south than to the north.

4) Permian—Late to post-tectonic emplacement of the Narragansett Pier and Westerly Granites near the end of a period of high heat flow.

5) Triassic and Jurassic—Regional cooling and uplift. Tensional, brittle faulting and hydrothermal activity producing the Lantern Hill fault zone.

6) Cretaceous to present—Gradual uplift and erosion.

ECONOMIC RESOURCES

The Westerly Granite has been used for dimension stone, particularly monumental granite, but none of the dikes of Westerly in the Mystic and Old Mystic quadrangles are large enough to be of economic value at present. The Narragansett Pier Granite has also been used for dimension stone, primarily in buildings, but is doubtful if any of the masses in the Old Mystic quadrangle are of sufficient size for economical quarrying. The Potter Hill Granite Gneiss, the Hope Valley Alaskite Gneiss, and phases of the Mamacoke Formation are a source of stone for foundations and for rip-rap. Rock from the large abandoned quarry of Mamacoke hornblende biotite gneiss at the northwest end of Mason Island was used as rip-rap for breakwaters in the Stonington area. Fine-grained phases of the Hope Valley Alaskite Gneiss, particularly near the Honey Hill fault, and some mylonitic rocks such as the felsic mylonite might be suitable for crushed stone. Where not too greatly folded, thin-bedded quartzite might be used for flagstone, facing stone, and in garden walls.

Silica is being mined at Lantern Hill for use in bottle glass because of its purity, primarily its low iron content. The soft, porous, vein quartz is the rock principally mined because of its ready crushability.

The Narragansett Pier and Westerly Granites have a noticeably higher radioactivity than other granites and granite gneisses of the region (Goldsmith and others, 1977). This is probably attributable to higher thorium content than the other rocks. The Permian granites in these quadrangles are too small in size, however, to be considered a source of radioactive materials.

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TABLE 1.—Selected modal analyses[1] of rocks from the Old Mystic quadrangle, Connecticut

			Preston Gabbro					Sterling Plutonic Group									Waterford Group				
Rock unit	Pnp	Pqm	Spg	Spg	Spd	Spqd	Spgd	Zhv	Zhv	Zhvf	Zhv	Zhvf	Zph	Zph	Zpha	Zmb	Zmb	Zmb	Zh	Za
Field number	(1203)	(1422)	(1139)	(1106)	(1042)	(1084)	(1051)	(1063)	(1301)	(1488)	(1418)	(1266)	(1299)	(1365)	(1400)	(907b)	(907c)	(1062)	(1473)	(927b)
Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17[4]	18	19[5]	20[6]
Quartz	26	16	—	0.2	<5	8	32	36	38	30	36	35	38	34	37	28	32	35	23	0.2
Plagioclase	35	39	31	40	43	59	41	35	32	42	31	33	32	32	32	55	48	48	50	43
Microcline	30	40	—	—	—	—	12	25	38	25	27	27	25	25	24	4	15	7	0.5	—
Biotite	6	3	—	—	5	3	10	2	+	1	4	5	4	8	6	9	4	8	13	12
Hornblende	—	1	65	56	32	19	—	—	—	—	—	—	—	—	—	2	—	—	11	43
Magnetite/ilmenite	1	0.3	4	0.3	9	3	0.7	0.5	1	1	0.7	0.4	—	0.5	0.5	0.8	0.8	0.8	0.2	1
Sphene	—	0.3	+	0.1	—	0.9	0.9	—	—	0.6	—	—	—	—	—	0.3	—	0.1	0.2	1
Apatite	0.3	0.1	—	0.1	5	0.4	0.2	+	—	+	+	+	0.1	0.1	0.2	0.4	0.2	0.2	0.2	0.3
Allanite	0.4	0.4	—	—	—	—	0.2	—	—	0.1	—	—	—	—	—	0.1	—	—	—	—
Zircon	0.1	—	—	—	—	—	—	0.1	0.7	+	—	—	—	—	—	+	0.1	+	—	—
Muscovite	0.8	—	—	—	—	—	0.3	1	+	—	1	0.1	0.2	0.4	0.1	—	0.1	0.4	—	—
Chlorite	0.1	—	0.1	2.6	—	4	—	+	—	—	—	—	0.3	0.3	—	—	0.3	0.3	—	—
Epidote	—	—	—	0.7	0.5	2	2	—	—	—	—	—	—	—	—	—	—	—	2.2	—
Other[2]	0.2[c]	—	—	—	+[r]	—	—	+[g]	—	+[r]	—	—	—	0.1[m]	—	+[r]	+[r]	0.4[c]	—	—
Approximate anorthite component of plagioclase[3]	22	14	53	55	38	38	43	12	5	7	15	23	22	1	25	n.d.	15	1	40	40

[1] Each mode is based on one thin section. Over 1,100 points counted per thin section; —, not present; + present but not among points counted.
[2] Other: c, calcite; g, garnet; m, monazite; r, rutile.
[3] ol, oligoclase; n.d., not determined.
Anorthite content determined by extinction angles measured in grains oriented perpendicular to a.
[4] Light-gray gneiss layer.
[5] Cataclastically deformed.
[6] Amphibolite with scattered light-colored feldspathic spots.

TABLE 2.—Selected modal analyses [1] of rocks from the Mystic quadrangle, Connecticut

Rock unit	Zmb	Zmb	Zmg	Zmb[2]	Zmhb	Zmhb	Zmhb[3]	Zma	Zhv	Zhv	Pw	Zp[4]
Field number	(800b)	(815a)	(847)	(762)	(843d)	(837a)	(896)	(852)	(853)	(845)	(841)	(823)
Sample number	1	2	3	4	5	6	7	8	9	10	11	12
Quartz	35	29	29	35	23	32	27	5	40	44	20	45
Plagioclase	50	48	65	35	54	45	37	38	32	29	48	28
Microcline	1	8	2	23	8	12	30	—	25	26	22	2
Biotite	13	10	3	6	8	7	5	—	2	0.8	8	24
Hornblende	—	3	—	—	5	2	—	53	—	—	—	—
Pyroxene	—	—	—	—	—	—	—	2	—	—	—	—
Magnetite/ ilmenite	0.3	0.9	0.7	0.1	1.0	1	0.1	0.4	0.1	0.1	0.4	0.4
Sphene	T	0.2	0.2	—	0.3	0.2	0.5	0.6	—	—	0.4	—
Apatite	—	0.4	0.2	0.1	0.2	0.4	0.2	0.5	T	—	0.3	0.2
Allanite	0.2	0.1	—	—	—	0.1	0.2	—	—	—	0.1	—
Zircon	T	0.1	T	T	—	T	—	T	—	T	0.1	T
Muscovite	—	0.1	0.1	—	—	—	—	—	—	0.2	0.1	—
Calcite	—	0.5	—	—	—	—	—	T	—	—	0.1	—
Garnet	—	—	—	—	—	—	—	—	T	—	—	T
Rutile	—	—	—	—	—	—	—	—	—	—	—	0.2
Approximate anorthite component of plagioclase	28	26	15	23	28	24	24	39	12	10	25–16[5]	26

[1] Each mode is based on one thin section. Over 1,100 points counted per thin section; —, not present; T, trace.
[2] Granitoid layer.
[3] Granitoid layer.
[4] Biotite-plagioclase-quarta gneiss layer in Plainfield Formation; a fairly abundant rock type in the Plainfield Formation.
[5] Plagioclase has oscillatory zoning, but overall has a more calcic core and less calcic shell.