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BEDROCK GEOLOGIC MAP OF THE NEW MILFORD QUADRANGLE, LITCHFIELD AND FAIRFIELD COUNTIES, CONNECTICUT

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The map and database of this report are available online at: http://pubs.usgs.gov/of/2003/of03-487/

On the cover:
Photograph of Lake Candlewood from Hubbell Hill in Sherman. View is to the south. Green Island and Deer Island are visible in the center of the view. The Vaughns Neck peninsula is visible on the left side of the photograph.

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INTRODUCTION

The bedrock geology of the New Milford quadrangle consists of Mesoproterozoic basement gneisses and Neoproterozoic to Ordovician metasedimentary and metavolcanic cover rocks intruded by Ordovician plutons. The basement rocks crop out within the New Milford massif, Sherman and Morrissey Brook inliers, and the Hudson Highlands (fig. 1). These massifs are collectively referred to as the "Highlands massifs" on the Connecticut State Bedrock Geological Map (Rodgers, 1985). In this report, the term "Hudson Highlands" describes only the Hudson Highlands massif proper. The easternmost limit of these massifs is west of Cameron's Line. Cameron's Line marks the present eastern limit of the exposures of autochthonous Cambrian-Ordovician Iapetan carbonate-shelf sequence in western New England and corresponds to a major Ordovician fault (Rodgers and others, 1959; Rodgers, 1971, 1985; Hatch and Stanley, 1973; Hall, 1980; Merguerian, 1987) that is interpreted as the approximate western limit for the source zone of the Taconic Allochthon (Stanley and Ratcliffe, 1985).

Apart from the State geologic map by Rodgers (1985), no geologic maps have been published that cover the entire area of the New Milford 7.5-minute quadrangle. Previous mapping in the vicinity includes work to the north by Dana (1977) in the Lake Waramaug area of the New Preston quadrangle and Jackson (1980) in the Kent quadrangle (fig. 2); to the northeast, Gates and Bradley (1952) mapped the New Preston quadrangle; to the south, Clarke (1958) mapped the Danbury quadrangle; to the east, Gates (1959) mapped the Roxbury quadrangle; and to the southeast, Stanley and Caldwell (1976) mapped the Newtown quadrangle. Sperandio (1974) mapped the Brookfield Gneiss in the southwestern part of the New Milford quadrangle. Rodgers (1985) compiled unpublished manuscript maps of parts of the New Milford quadrangle by K.G. Caldwell and G.V. Carroll and the Connecticut part of the Pawling, New York quadrangle by R.A. Jackson for the State map. The map of the Poughquag 7.5-minute quadrangle, New York, two quadrangles to the west, represents the closest recent mapping in the eastern Hudson Highlands (Ratcliffe and Burton, 1990).

The Water Resources office of the USGS in Hartford, Connecticut compiled an unpublished GIS database of driller's well completion reports for parts of the towns of New Milford and New Fairfield, Connecticut. The locations of these wells are shown on Plate 1. The database was evaluated for bedrock type as reported by the driller (Appendix). Neither the quality of the data, nor the accuracy of the well logs has been evaluated. The logs were examined in an attempt to constrain the extent of the Stockbridge Formation in the northern part of the map. Inconsistencies in the data are evident on the map compilation (Appendix), however, the large number of wells completed in "limestone" in the north-central part of the map suggest that the data are somewhat useful. The well driller's reports include descriptions of general rock types or simply rock colors. The reports could not be used with reliability to distinguish most rock types, therefore, only reports with "limestone" identified were used in this study.

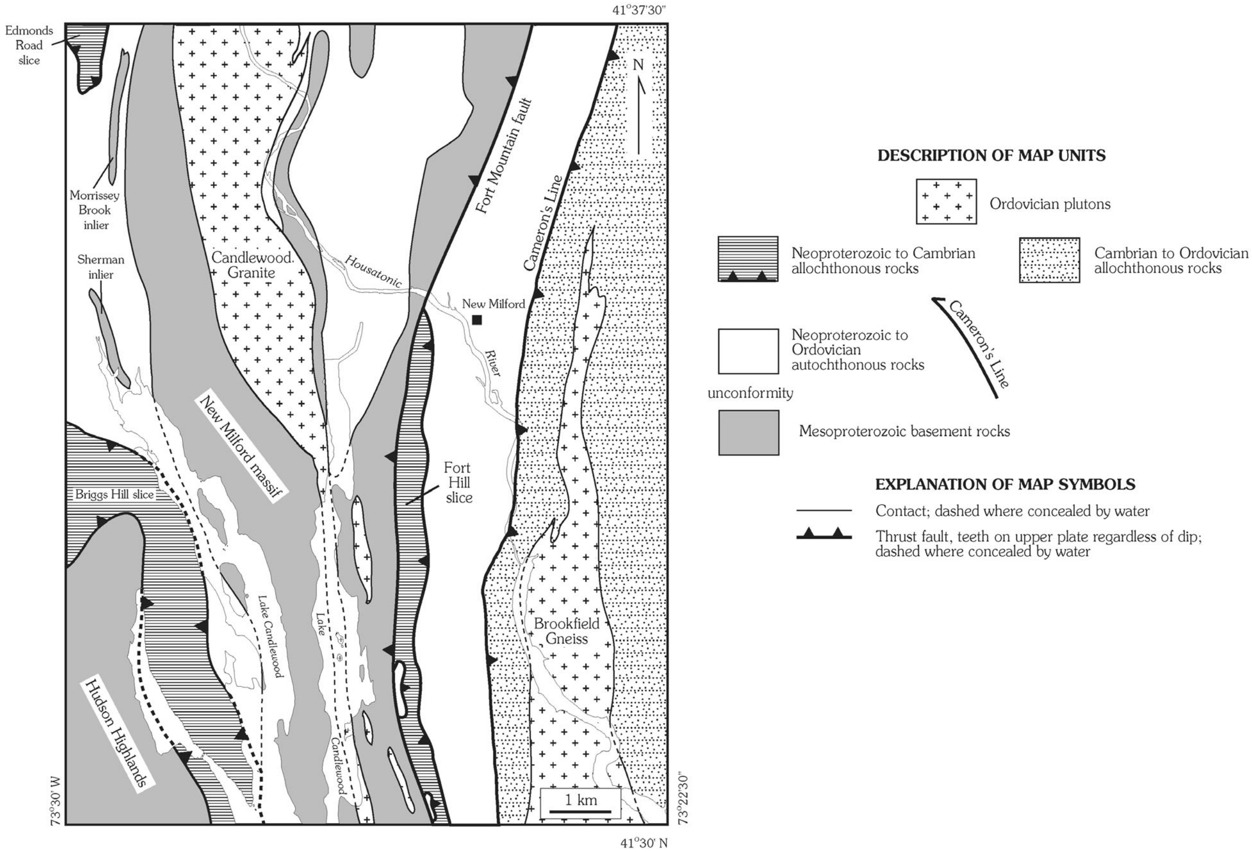


Figure 1. Simplified geologic map of the New Milford quadrangle.

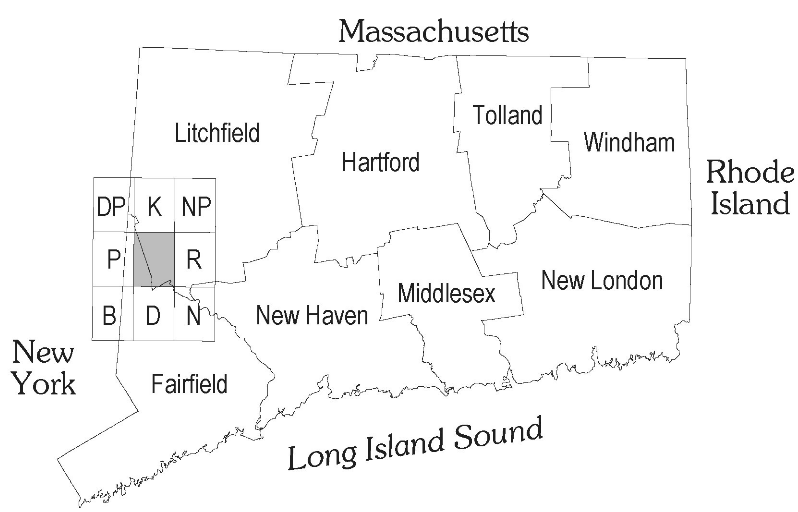


Figure 2. Index map showing the location of the New Milford quadrangle (gray box) in Fairfield and Litchfield Counties, Connecticut. Adjacent 7.5-minute quadrangles include Dover Plains, NY-CT (DP), Pawling, NY-CT (P), Brewster, NY-CT (B), Danbury, CT (D), Newtown, CT (N), Roxbury, CT (R), New Preston, CT (NP), and Kent, CT (K).

STRATIGRAPHY

West of Cameron's Line, an autochthonous and allochthonous cover sequence overlies Mesoproterozoic basement gneiss in the New Milford quadrangle. Allochthonous rocks include the Manhattan Schist and autochthonous rocks include the Dalton, Stockbridge, and Walloomsac Formations. The application of the terms autochthonous and allochthonous to these formations follows the usage of Harwood (1979) for correlative rocks in the Norfolk quadrangle, northwestern, Connecticut. East of Cameron's Line, rocks of the Ratlum Mountain and Rowe Schists comprise a Lower Paleozoic allochthonous section (Rodgers, 1985).

MESOPROTEROZOIC GNEISS

Mesoproterozoic basement gneiss of the New Milford massif, Hudson Highlands, and Sherman and Morrissey Brook inliers is exposed throughout the western half of the quadrangle. Rocks in the southwestern corner of the map represent the northeasternmost exposures of the Hudson Highlands. Walsh and others (in press) have demonstrated a Mesoproterozoic age for a number of the units within the basement of the New Milford quadrangle.

The basement rocks are subdivided into seven units that include, from oldest to youngest: 1) layered biotite gneiss (Ybg), 2) calc-silicate rock (Ycs), 3) hornblende gneiss and amphibolite (Yhg), 4) pink granite gneiss (Ygg), 5) biotite granitic gneiss (Ybgg), 6) Danbury augen granite of Clarke (1958) (Yag), and 7) migmatite gneiss (OYmig).

Layered biotite gneiss (Ybg)

Layered biotite gneiss (Ybg) is the most widespread rock of the basement gneisses. It consists of well-layered feldspathic gneiss, amphibolite, quartz-rich gneiss, and rare vitreous quartzite and calc-silicate gneiss. The unit is interpreted as a paragneiss with abundant layer-parallel sills of granitic gneiss. It passes into migmatitic gneiss (OYmig), which is in part inherited from Ybg, and contains many leucocratic layers.

Light-gray leucocratic biotite-microcline-quartz-plagioclase granitic gneiss occurs everywhere within the Ybg unit as layers ranging from centimeters to meters thick. The layering of the leucocratic gneiss is generally sub-parallel to the dominant foliation in the rock, but lenses of the leucocratic gneiss locally converge and appear to cross-cut interlayered amphibolite and paragneiss. Cross-cutting relations are rarely exposed and relative age relations of the leucocratic gneiss layers within the Ybg are often equivocal. These leucocratic layers could therefore represent either metasedimentary or metavolcanic rocks, or lit par lit intrusive or metasomatic layers. Parts of Ybg predate intrusion of a pink granite gneiss (Ygg) and are, therefore, older than 1311 Ma (see below).

Zircons from a 30 cm thick layer of leucocratic biotite granite gneiss that is bounded by 20 cm and 10 cm thick layers of amphibolite on Long Mountain were analyzed by the U-Pb technique on the Sensitive High Resolution Ion Microprobe (SHRIMP). The sample yielded an age of 1048 ± 11 Ma (Sample NM772, Walsh and others, in press). This age is Ottawan (McLelland and others, 2001) and suggests that the sampled layer is intrusive or migmatitic leucosome.

Typical exposures of the layered biotite gneiss occur in the Sherman inlier east of Allens Cove and in the Morrissey Brook inlier. In the New Milford massif typical exposures occur on the west side of Towner Hill, on Long Mountain, and on Carmen Hill.

Calc-silicate rock (Ycs)

Calc-silicate rock is exposed in an abandoned quarry on the east side of Candlewood Mountain, where it is in sharp contact with the layered biotite gneiss (Ybg) to the west and the biotite-sillimanite schist of the Dalton Formation (CZd) to the east. This belt marks the only mapped occurrence of calc-silicate rock within the New Milford quadrangle. Small, unmapped pods of calc-silicate rock are rare elsewhere within the basement gneisses. Two larger belts of calc-silicate rock have been mapped within the basement rocks to the north in the Kent quadrangle: one in the New Milford massif and another in the Housatonic Highlands (Jackson, 1980). To the south in the Danbury quadrangle, Clarke (1958) also reports calc-silicate rock within the basement, but only as unmapped minor bodies.

Hornblende gneiss and amphibolite (Yhg)

Two large belts of hornblende gneiss and amphibolite (Yhg) occur in the northern and southwestern parts of the map. Many smaller mapped areas of these rocks, as well as those too small to map separately, occur throughout the layered biotite gneiss (Ybg) and migmatite gneiss (OYmig). Xenoliths of mafic rocks also occur within the pink granite gneiss (Ygg) and Danbury augen granite (Yag). The belt of Yhg in the southwestern corner of the map is generally coarse-grained and weakly foliated, and may be in part intrusive. This southwestern belt continues into the Danbury quadrangle (Clarke, 1958) to the south where it occupies a much larger area than any of the hornblende gneiss and amphibolite bodies in the New Milford quadrangle. Clarke (1958) reports that some of this coarse-grained hornblende gneiss is olivine gabbro (troctolite) and diorite that may be co-magmatic. With the exception of this belt, most of the Yhg unit is well foliated and well layered, suggesting that the protolith may have been basaltic volcanic or volcaniclastic rock.

Typical exposures of Yhg occur along the west side of Buck Rock Road in New Milford and in the vicinity of Short Woods in New Fairfield.

Pink granite gneiss (Ygg)

Pink granite gneiss (Ygg) crops out in three belts within the quadrangle; a northern belt on Mt. Tom that extends into the Kent quadrangle (Jackson, 1980), a belt on Hubbell Hill, and a thin belt that extends south from Wanzer Mountain. All three bodies are well foliated and have a generally uniform texture and composition. Contacts with the adjacent units are not exposed. Ygg contains xenoliths of layered biotite gneiss (Ybg) and amphibolite (Yhg), however, and is interpreted as an intrusive body. A sample collected on the East Aspetuck River yields a U-Pb zircon SHRIMP age of 1311 ± 7 Ma (Sample NM174, Walsh and others, in press). Although limited ages were available to early workers, both Clarke (1958) and Hall and others (1975) considered similar granite gneisses in their study areas to be among the oldest granitic rocks in the eastern Hudson Highlands and western Connecticut massifs. Dana (1977) and Jackson (1980) interpreted the pink granite gneiss unit as the youngest basement gneiss and stated that it cut all other rocks in the basement. However, previously unrecognized Ordovician pink granitic gneiss also occurs in the basement of the New Milford area (Sample NM576A, Walsh and others, in press), and it is possible that some of these younger granitic rocks were mapped as

Precambrian rocks thus leading to the confusion. The 1311 Ma age comes from the northern belt of Ygg on this map that extends into the Kent quadrangle on the west side of Mt. Tom. Although the two other belts on Hubbell Hill and Wanzer Mountain appear similar to the dated rock, the possibility exists that these two belts could be younger Ordovician pink granite gneiss. The xenoliths of Ybg and Yhg, as well as the contact relations, suggest that the major paragneiss unit Ybg and the host of OYmig are older than 1311 Ma.

Typcial exposures of Ygg occur on Wanzer Mountain east of Pine Ledge, on the west side of a jeep trail in Pootatuck State Forest south of Worden Brook, on the southeast slopes of Hubbell Hill northeast of Haviland Millpond, on the west side of Paper Mill Road, on the east slopes of Mt. Tom, and at the dated locality in the East Aspetuck River, approximately 800 m south of the summit of Mt. Tom.

Biotite granitic gneiss (Ybgg)

The biotite granitic gneiss (Ybgg) is a well-foliated, moderately layered, gray biotite-microcline-quartz-plagioclase gneiss with a generally uniform texture and composition. It occurs as a single map unit in the New Milford massif, northwest of downtown New Milford. Contacts with the adjacent Ybg unit are not exposed, but Ybgg is interpreted as an intrusive body into Ybg. It resembles the thin layers of leucocratic biotite gneiss found elsewhere within the Ybg unit discussed above, but it does not possess the compositional heterogeneity associated with Ybg. A sample from the biotite granitic gneiss unit yielded a U-Pb zircon SHRIMP age of 1050 ± 14 Ma (Sample NM628, Walsh and others, in press).

Typical exposures of the biotite granitic gneiss occur on an unnamed hill in New Milford between the West Aspetuck River and the East Aspetuck River approximately 1 km north of the Wannuppee Islands on the Housatonic River.

Danbury augen granite of Clarke (1958) (Yag)

Clarke (1958) named the Danbury augen granite for exposures on the west side of Lake Candlewood in the towns of Danbury and New Fairfield, Connecticut. Contacts with the adjacent rock units are not exposed, but the augen granite contains xenoliths of amphibolite, hornblende gneiss, layered biotite gneiss, and pink granite gneiss. This unit occurs in three large belts in the map area, and several smaller bodies. The largest body is a pluton exposed in the southwestern part of the map, west of Lake Candlewood, that is coextensive with Clarke's (1958) type locality to the south. Two smaller plutons intrude the gneisses of the New Milford massif along its eastern margin, and one of these, at Mt. Tom, extends into the adjacent Kent quadrangle to the north (Jackson, 1980). Unlike the larger pluton in the southwestern part of the quadrangle, the two smaller bodies to the northeast are highly deformed and mylonitized along the Fort Mountain fault which is parallel to the dominant S2 foliation. This fault forms the eastern border of the New Milford massif. A sample of the Danbury augen granite from the west side of Pond Mountain in the southwestern corner of the map yielded a U-Pb zircon SHRIMP age of 1045 ± 8 Ma (sample NM100, Walsh and others, in press).

Typical exposures of weakly deformed Danbury augen granite occur on Pond Mountain, Wanzer Mountain, and Pine Ledge. Mylonitized Yag is exposed at outcrops along the east side of Fort Mountain and Mt. Tom.

Migmatite gneiss (OYmig)

The migmatite gneiss (OYmig) unit consists of stromatic migmatite containing very well-layered, gray biotite-microcline-quartz-plagioclase gneiss, biotite-quartz-plagioclase gneiss, and amphibolite with abundant layer-parallel white to pink leucosomes of granitic pegmatite and granitic gneiss. The host rock for the migmatite gneiss is the layered biotite gneiss unit (Ybg). The contact between these units is gradational over a distance of tens of meters and is defined based on the greater abundance of leucosomes within the migmatite gneiss. Locally, the migmatite is dominated by leucosomes to the extent that the original character of the host rock is almost completely replaced. In addition to abundant layer-parallel leucosomes, the migmatite gneiss contains abundant dikes and veins of light gray to pink granitic gneiss, aplite, and pink migmatitic granite gneiss that post-date Mesoproterozoic deformation. These younger intrusions have the same style of deformation and contain the same dominant fabric (F2 folds and S2 foliation) found in the cover sequence rocks and Ordovician granites. U-Pb zircon SHRIMP ages of 1057 ± 10 Ma (sample NM576B) and 444 ± 6 Ma (sample NM576A) from samples collected northwest of Green Pond indicate Mesoproterozoic and Ordovician ages for the different generations of migmatite (Walsh and others, in press). These field relations and U-Pb zircon ages suggest that the migmatite gneiss (OYmig) has a composite history consisting of Mesoproterozoic migmatization by anatexis, followed by Ordovician migmatization by injection. A single map unit labeled Ymig is shown in the southwestern corner of the map. There the unit consists of stromatic migmatite gneiss and well-foliated granitic gneiss without the abundant younger injection migmatite and dikes seen in the central part of the map. This area of migmatization may be locally related to the Danbury augen granite (Yag).

Typical exposures of the migmatite gneiss occur along the private road to Green Pond and Great Mountain, on Green Island, On Deer Island, on the north end of Towner Hill, and on the east slopes of Vaughns Neck. To the south in the Danbury quadrangle, Clarke (1958) described similar rocks on Vaughns Neck and Pine Island but mapped them as younger granite or Fordham Gneiss, respectively.

ALLOCHTHONOUS ROCKS WEST OF CAMERON'S LINE

Manhattan Schist

Rocks of the Neoproterozoic to Cambrian Manhattan Schist crop out in three thrust slices (Edmonds Road, Briggs Hill, and Fort Hill slices; see fig. 1) in the central and western part of the area. The age of the Manhattan Schist is not directly known, but is presumed to be Neoproterozoic to Cambrian based on regional correlations with rocks that contain Iapetan rift-related volcanic rocks (Baskerville, 1992; Rodgers, 1985; Walsh and Aleinikoff, 1999). The presence of amphibolites in the Manhattan Schist suggests that the rocks are, in part, correlative with rift-related or transitional metabasalts in the Iapetan margin cover sequence of the northern Appalachians (Coish and others, 1985, 1986, 1991; Coish, 1989; Ratcliffe, 1987), thus the lower age limit of the rocks may be Neoproterozoic (Kumarapeli and others, 1989; Walsh and Aleinikoff, 1999). On the State bedrock geologic map (Rodgers, 1985), the name Manhattan Schist was used for these rocks in the New Milford quadrangle, and its usage is continued here. In northern Connecticut (Rodgers, 1985) and Massachusetts (Zen and others, 1983), the name Hoosac Schist or Hoosac Formation is used for these rocks. Rocks of the Canaan Mountain Schist (Rodgers, 1985) or the lower thrust slice of the Canaan Mountain Formation (Harwood, 1979) are also potentially correlative. Earlier workers considered these rocks as Member C of the Manhattan Schist (Dana, 1977; Jackson, 1980), or Members B and C of the Manhattan Schist with Member B consisting of the amphibolite unit (Hall, 1968a, 1968b, 1976).

The Manhattan Schist consists of two map units, biotite schist (CZm) and amphibolite (CZma). The biotite schist is very coarse grained and typically contains porphyroblasts of sillimanite and/or garnet. Abundant quartz-feldspar leucosomes, pegmatite, and quartz veins are characteristic of the unit. Typical exposures occur in cuts along Connecticut Route 39 and on the west side of Briggs Hill in the Briggs Hill Slice, on Fort Hill in the Fort Hill slice, and in outcrops on both sides of Edmonds Road in the Edmonds Road slice. Several thin continuous belts of amphibolite (CZma) occur within the schist of the Briggs Hill and Fort Hill slices. The amphibolites are interpreted as metabasalts or metabasaltic volcaniclastic rocks. Volcanic textures, however, were not observed in any of the amphibolites. Typical exposures of the amphibolite occur in roadcuts near the junction of Leach Hollow Road and Route 39 in Sherman. Amphibolite horizons are generally a few meters thick within the Fort Hill slice, but tens of meters thick in the Briggs Hill Slice.

The map distribution of the Manhattan Schist differs from that shown on the State map (Rodgers, 1985). In most areas, the difference is the result of detailed mapping where none was available to Rodgers for his compilation. In the valley of Squantz Pond, however, this map shows the Manhattan Schist in contact with the rocks of the Hudson Highlands massif where Rodgers (1985) showed a belt of Walloomsac Formation between the basement and the allochthonous rocks. There is no outcrop in this belt so the map pattern here is interpretive and agrees with the work of Clarke (1958) in the Danbury quadrangle, where Manhattan Schist in shown in contact with the basement.

AUTOCHTHONOUS ROCKS WEST OF CAMERON'S LINE

Neoproterozoic to Early Paleozoic rocks form an autochthonous metasedimentary cover sequence above the Mesoproterozoic basement rocks in the central and western part of the quadrangle. The sequence from the base up includes the Neoproterozoic to Cambrian Dalton Formation, the Cambrian to Ordovician Stockbridge Formation, and the Ordovician Walloomsac Formation. The basal Dalton Formation rests unconformably upon the Mesoproterozoic basement gneisses (Zen and others, 1983; Rodgers, 1985). The upper age of the Dalton Formation is constrained in Massachusetts by the Early Cambrian Cheshire Quartzite, dated on the presence of *Olenellus* fragments (Walcott, 1888), which overlies the Dalton Formation. The lower age limit of the Dalton Formation is not firmly established, and it may range into the Neoproterozoic (Ratcliffe, 1974; Zen and others, 1983). In Massachusetts, the Stockbridge Formation overlies the Early Cambrian Cheshire Quartzite and underlies the Middle Ordovician Walloomsac Formation, thus the age of the Stockbridge is considered Early Cambrian to Early or Middle Ordovician (Zen 1966; Ratcliffe, 1974; Zen and others, 1983; Ratcliffe and others, 1993). Late Middle to early Late Ordovician fossils constrain the age of the Walloomsac Formation in New York and Massachusetts (Potter, 1972; Ratcliffe, 1974; Finney, 1986; Ratcliffe and others, 1999). In this quadrangle, the Walloomsac Formation unconformably overlies the Dalton and Stockbridge Formations and the Precambrian gneisses. Locally, the Dalton and Stockbridge Formations were eroded away prior to the deposition of the Walloomsac Formation along a Middle Ordovician unconformity during the earliest stages of the Taconic Orogeny (Zen, 1967; Rodgers, 1971, 1985; Jacobi, 1981).

Previous workers to the north and south used the names Lowerre Quartzite (Dana, 1977; Jackson, 1980) or Manhattan Formation (Clarke, 1958) for the Dalton Formation, Inwood Marble (Clarke, 1958; Dana, 1977; Jackson, 1980) for the Stockbridge Formation, and Manhattan A (Dana, 1977; Jackson, 1980) or Manhattan Formation (Clarke, 1958) for the Walloomsac Formation. Zen and others (1983) and Rodgers (1985) use the names Dalton, Stockbridge, and Walloomsac on the State geologic maps of Massachusetts and Connecticut, respectively, and this nomenclature is applied in this report.

Dalton Formation

Rocks of the Dalton Formation crop out in a large belt in the north-central part of the area, and in several smaller, isolated, belts in the south central and western parts of the map. The Dalton Formation consists of two map units: sillimanite-biotite schist (CZd), and quartzite and small pebble conglomerate (CZdq). The schist unit (CZd) is the most abundant and consists of interbedded schist and lesser tan feldspathic granofels. Harwood (1979) reports similar lithologies in the Norfolk quadrangle, but there, the schist is subordinate to the granofels. Porphyroblastic knots of fibrolitic sillimanite, quartz, and muscovite characterize the schist, but are not ubiquitous. Typical exposures occur along the prominent, unnamed ridge south of Long Mountain to the Housatonic River. Layers of mapped quartzite and small pebble conglomerate (CZdq) crop out within the schist, and occur locally above the unconformity with the basement gneisses. Typical exposures of CZdq occur on an unnamed knob 0.5 km northwest of Fort Hill and on the southwest side of Deer Island.

Stockbridge Formation

Rocks of the Stockbridge Formation crop out in four synclines in the central part of the area and in a xenolith within the Candlewood Granite. The main unit in the Stockbridge Formation is a massive to thickly bedded dolomite marble. The marble is poorly exposed throughout the area and natural outcrops are sparse. The dominance of dolomite marble in the New Milford quadrangle suggests that the Stockbridge Formation here is correlative with the lowermost, or Cambrian, part of the formation regionally (Zen, 1966; Hall, 1968a; Ratcliffe, 1974; Ratcliffe and others, 1993). If this correlation is valid, it suggests that the upper part of the Stockbridge has been eroded away. All the Stockbridge of this quadrangle, therefore, may be entirely Cambrian and separated from the overlying Walloomsac Formation by an unconformity. The upper contact between the Stockbridge and the Walloomsac, however, is not exposed in the quadrangle.

The broad area of the Housatonic Valley south of downtown New Milford is underlain by dolomite marble, and this same belt continues to the north-northeast, generally parallel to U.S. Route 202. The marble is well exposed in quarries northeast of Boardman Bridge, where it is currently being crushed and washed for sand. The syncline at Merryall Brook in the north central part of the map contains no exposed marble in this quadrangle; its extent is constrained by domestic water well logs (see Appendix), and outcrops in the adjacent Kent quadrangle (Jackson, 1980).

A large xenolith of Stockbridge and Dalton Formations occurs within the Candlewood Granite north of Boardman Mountain, at Tory's Cave which is shown as "k", on Plate 1. There, the Stockbridge consists of well-bedded gray and white calcite and dolomite marble. The entrance to Tory's Cave is located within the marble and follows the plunge of F2 folds into the hillside. The cave is reportedly the third largest in Connecticut (Yale Speleological Society, 1963). Tory's Cave is the only known cave in the Stockbridge Formation in the quadrangle. Karren, or solution grooves, on outcrop surfaces are the only other karst features seen in the area during the course of mapping.

A feldspathic quartzite (OCsq) is exposed at only one roadcut on the west side of U.S. Route 202 in the northeastern part of the quadrangle. The rock is apparently surrounded by the Stockbridge Formation, but contacts with the surrounding dolomite marble are not exposed. A similar rock is reported from the Kent quadrangle to the north, where it was mapped as a unit within Member A of the Inwood Marble (Jackson, 1980). The rocks resemble the feldspathic quartzite and granofels horizons present within the bulk of the Dalton Formation.

Walloomsac Formation

Rocks of the Walloomsac Formation crop out in the western part of the map. The main unit in the Walloomsac Formation is biotite schist with fibrolitic sillimanite (Ow). In places where sillimanite occurs as porphyroblastic knots, the biotite schist unit resembles the schist unit in the Dalton Formation. In such situations, the identity of the schist is best determined through its association with other rocks in the sequence. The Dalton Formation contains more feldspathic granofels layers than the Walloomsac, and quartzites found in the Dalton are generally absent from the Walloomsac. Conversely, calc-silicate pods are more common in the Walloomsac Formation than they are in the Dalton.

The second map unit in the Walloomsac Formation is calcite marble (Owm) that occurs as meter-thick to tens-of-meters-thick layers within the schist that are locally traceable for more than 2 kilometers. These calcite marble horizons are absent from the Dalton Formation. Natural exposures of marble generally occur as rounded rusty orange to tan weathering outcrops. Karst features include rarely observed karren (solution grooves) and a single cave located east of Edmonds Road in Sherman (shown as "k" on Plate 1).

The base of the Walloomsac Formation is known to be a major regionally extensive unconformity outside this quadrangle. Along the west side of Barnes Hill and southward along the west side of Lake Candlewood, the Walloomsac rests on either the Mesoproterozic gneiss or on rocks of the Dalton Formation without the intervening Stockbridge Formation. This contact is interpreted as the regional unconformity.

ALLOCHTHONOUS ROCKS EAST OF CAMERON'S LINE

Rocks of the Cambrian to Ordovician Ratlum Mountain and Rowe Schists crop out in the eastern part of the quadrangle, east of Cameron's Line. Early workers used the name Hartland Formation for these rocks (Rice and Gregory, 1906; Clarke, 1958; Gates, 1959; Gates and Martin, 1976; Hall, 1976), but our usage follows that of the more recent State bedrock geologic map (Rodgers, 1985). The distribution of the rock types in the two formations within the New Milford quadrangle suggests that they are part of an interlayered metasedimentary sequence with gradational contacts. Ultramafic rocks reported elsewhere within the Rowe Schist (Rodgers, 1985) were not seen during the course of mapping in the New Milford quadrangle. The age of these units is not directly known, nor is their relative age, but it is presumed to be Early Cambrian to Early Ordovician based on regional correlations (Zen and others, 1983; Rodgers, 1985; Stanley and Hatch, 1988). Sevigny and Hanson's (1995) age of the Brookfield Gneiss (451 ± 1 Ma) and Walsh and others' (in press) age of a leucogranite dike (453 ± 6 Ma) that cuts the Brookfield Gneiss provide minimum age constraints because these intrusive rocks post-date the first two periods of deformation recorded in the rocks east of Cameron's Line.

Ratlum Mountain Schist

The Ratlum Mountain Schist consists of three units: 1) schist (OCr), 2) amphibolite (OCra), and 3) coarse kyanite schist (OCrk). The schist unit (OCr) is the most widespread and consists of muscovite-biotite-plagioclase-quartz schist with variable amounts of staurolite, kyanite, and/or garnet porphyroblasts. Schist near the contact with the Brookfield Gneiss and schist xenoliths within the gneiss, especially on Wolf Pit Mountain, contain sillimanite. Feldspathic granofels interlayered with the schist are interpreted as primary psammitic beds within a largely pelitic sequence. Several laterally continuous belts of amphibolite (OCra) of variable thickness within the schist unit are interpreted as metabasalts. Typical exposures of the schist occur at the narrows of the Housatonic River at Lovers Leap. A well-exposed amphibolite also crops out at Lovers Leap, where it increases in thickness to the north across the river and traces up the ridge and along the west side of an unnamed hill. A single horizon of schist with coarse kyanite porphyroblasts (OCrk) crops out in the southeastern part of the map on the west side of Rocky Hill. The coarse kyanite schist could be a metamorphosed aluminous metapelite, or possibly a metasomatic rock as it is closely associated with mappable quartz veins.

Rowe Schist

The Rowe Mountain Schist consists of two units: 1) garnetiferous schist (OCrg), and 2) feldspathic granofels and biotite schist (OCrfq). The garnetiferous schist unit (OCrg) is the most widespread and consists of rusty weathering muscovite-biotite-plagioclase-quartz schist with abundant 1 cm garnet porphyroblasts and variable amounts of staurolite and/or kyanite porphyroblasts. The garnetiferous schist (OCrg) is gradational by intercalation with the main schist unit in the Ratlum Mountain Schist (OCr). Typical exposures of the garnetiferous schist occur south of Reservoir No. 4 in New Milford and southeast of Mead Corners in Bridgewater. The feldspathic granofels and biotite schist unit (OCrfq) crops out in a single mapped horizon within the garnetiferous schist southwest of Reservoir No. 4 in New Milford. The OCrfq unit is gradational by intercalation with the garnetiferous schist and resembles smaller unmapped feldspathic granofels layers found within both OCrg and OCr.

ORDOVICIAN INTRUSIVE ROCKS

Ordovician intrusive rocks occur throughout the New Milford quadrangle. Two large plutons consisting of the Brookfield Gneiss and Candlewood Granite, occur east and west of Cameron's Line, respectively. Many smaller dikes of diorite, granite, and pegmatite occur throughout the area, and these are shown as small lens-shaped map units or as strike and dip symbols on the geologic map (Plate 1). Quartz veins in the area are shown as map units or as map symbols on the geologic map (Plate 1).

Brookfield Gneiss

Rocks of the Brookfield Gneiss crop out in the eastern part of the map, east of Cameron's Line. The Brookfield Gneiss consists largely of biotite-hornblende-plagioclase dioritic gneiss (Obd). The Brookfield Gneiss intrudes the rocks of the Rowe Schist, as indicated by the presence of xenoliths within the pluton. The map pattern suggests that the Brookfield also intrudes the Ratlum Mountain Schist, but direct evidence such as xenoliths was not observed. The geologic map (Plate 1) shows subdivisions within the Brookfield Gneiss that are based on a detailed petrologic and geochemical study by Sperandio (1974, p. 51). The new mapping did not duplicate Sperandio's petrologic and chemical efforts, nor did it test the validity of his internal contacts within the large pluton. According to Sperandio (1974), the sub-units within the main pluton of Brookfield Gneiss range in composition from diorite to granite. In the field, the Brookfield Gneiss is a dark gray to black and white, medium- to coarse-grained, non-foliated to well foliated, locally layered dioritic gneiss. Where the gneiss is layered, compositional banding of light and dark colored gneiss is generally parallel to the dominant foliation. It is unclear if this banding is tectonic or igneous. In accordance with Sperandio (1974), the new mapping finds that the Brookfield Gneiss is generally well foliated along the margin of the large pluton and poorly foliated to rarely non-foliated in the core. Sperandio (1974) noted that the large pluton of Brookfield Gneiss is not fine grained along the margins, suggesting a lack of a chill margin, and that intrusion of the Brookfield occurred while the country rocks were hot. Sperandio (1974) also noted a general absence of hornfels, except at a few small localities, around the Brookfield Gneiss. Anomalous granoblastic textures in sillimanite bearing metasedimentary rocks at two locations around the Brookfield Gneiss (see section on Metamorphism) suggest that the sillimanite is a product of locally preserved contact metamorphism. Dikes of Brookfield Gneiss in the Ratlum Mountain Schist that were not mapped by Sperandio (1974) are indicated on the map as "Obd", and they all have a dioritic composition. The age of the Brookfield Gneiss, from a sample of biotite quartz diorite collected in the Danbury quadrangle, is 451 ± 1 Ma (Sevigny and Hanson, 1995). Typical exposures of the Brookfield Gneiss are located on the northeast side of Wolf Pit Mountain, between the elevations of 300 and 450 feet in Town Farm Brook, and along Hemlock Road in Bridgewater.

Granite

The majority of the granite in the quadrangle occurs as the Candlewood Granite (Ogc), a large elongate pluton that extends north-south through the area and into the adjacent Kent and Danbury quadrangles. A number of smaller plutons and dikes of granite also occur in the area; they are shown with the symbol "Og" on Plate 1. The name Candlewood Granite is redefined here and in Walsh and others (in press). Gregory and Robinson (1907) originally used the term Thomaston Granite to define numerous granitic bodies in western Connecticut. In the Kent quadrangle, Jackson (1980) used the term Candlewood Lake Pluton to specifically describe the large intrusive body that passes through Lake Candlewood. Since that time, others have used both the terms Candlewood Lake Pluton and Candlewood Lake granite to refer to this intrusive body (Mose and Wenner, 1980; Amenta and others, 1982; Mose and Nagel, 1982; Amenta and Mose, 1985). Although the granite does pass through Lake Candlewood (not Candlewood Lake), it is poorly exposed along the lake. The new mapping shows that the type locality of the granite is more properly located at Candlewood Mountain. For this reason, the abbreviated term Candlewood Granite is used here. Typical exposures of the Candlewood Granite occur on the Candlewood Trail on Candlewood Mountain, which is almost entirely underlain by the granite.

The Candlewood Granite and the smaller granite bodies are all well foliated, fine- to medium-grained, muscovite-biotite-quartz-plagioclase-microcline granite. Locally, the Candlewood Granite contains phenocrysts (up to 1 cm) of microcline, and irregular compositional banding that is interpreted as igneous flow foliation. Igneous flow foliation within the Candlewood Granite is generally deformed by Paleozoic F2 folds. The most conspicuous planar fabric within the Candlewood Granite and the smaller intrusive bodies is the S2 foliation. The granite bodies are considered syn-tectonic with respect to the Paleozoic D2 deformation because they post-date some F2 folds in the country rock, yet contain F2 folds of folded igneous flow foliation. The granites have the S2 foliation as the dominant fabric, and generally intrude along the axial surface of F2 folds, sub-parallel to the regional trend of the S2 foliation. A possible explanation for the presence of D2 fabrics both in and out of the granites may be that the D2 structures developed within the intrusion represent a stress field before and during intrusion, and that D2 structures in the country rock experienced post-intrusion tightening within the same stress field. The U/Pb zircon SHRIMP age of the Candlewood Granite is 443 ± 7 Ma (Walsh and others, in press). A granite dike (Og) that cuts the Brookfield Gneiss south of Town Hill yields a U/Pb zircon SHRIMP age of 453 ± 10 Ma (Walsh and others, in press), the same age as the dated Brookfield Gneiss from the Danbury quadrangle (451 ± 1 Ma, Sevigny and Hanson, 1995) within uncertainty.

In the Danbury quadrangle to the south, Clarke (1958) mapped a large area in the north central part of his map as “younger granite”. The new mapping shows that the Ordovician granite correlates with Clarke’s “younger granite”, but his younger granite is far less extensive than indicated on his map, at least at the Danbury – New Milford quadrangle boundary. Clarke’s younger granite included areas with “over 50 percent” (Clarke, 1958, p. 38) granite. Mapping in the New Milford quadrangle shows that the granite can be separated from the basement gneisses on Vaughns Neck and Carmen Hill. There, the basement gneisses generally exhibit greater lithologic variability across strike, and locally preserve older Mesoproterozoic folds not seen in the Ordovician granites. Rodgers (1985) re-interpreted the “younger granite” of Clarke (1958) as Mesoproterozoic basement gneiss. The new mapping in New Milford suggests that the area in the Danbury quadrangle first shown as “younger granite” (Clarke, 1958) and later interpreted as basement gneiss (Rodgers, 1985) is most likely a combination of both rocks that have not yet been mapped separately. The designation by Rodgers as Mesoproterozoic, therefore, should be retained based on the identification of the host rock to the igneous intrusion.

Pegmatite

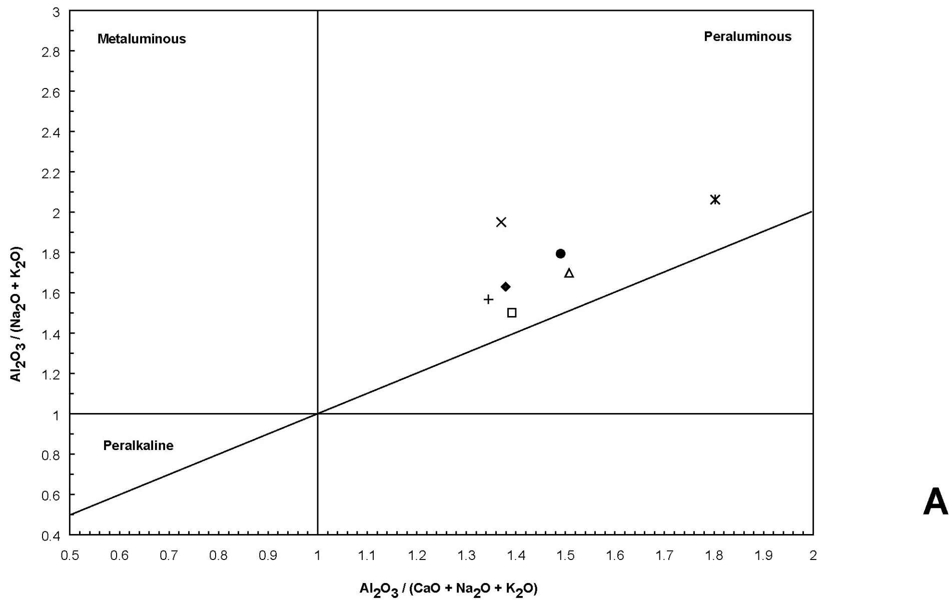
Mapped dikes of pegmatite occur throughout the rocks in the central and western part of the area. These dikes are granitic and appear to have the same relationship to the surrounding rocks as the granite dikes and, therefore, most are interpreted as Ordovician. Additional outcrop-sized or smaller, irregularly shaped areas of pegmatite also occur within most of the rocks west of Cameron’s Line, excluding the Stockbridge Formation. These areas have not been mapped separately either because they are too small, have no consistent tabular orientation, or are discontinuous. It is likely that some of the small, unmapped pegmatites in the Mesoproterozic rocks are Mesoproterozoic in age.

Quartz Veins

Quartz veins in the area are shown as small lens shaped map units or as strike and dip symbols on the geologic map (Plate 1). Two mapped garnet-biotite-quartz veins crop out on the west side of Rocky Hill in the southeastern corner of the map. The two mapped veins are 2 m thick and traceable for approximately 100 m, parallel to the S2 foliation. A small mine occurs in the easternmost quartz vein along the Silica Mine Trail in the Sunny Valley Preserve (not labeled on map). According to John Pawloski (personal commun., 2003), director of the Connecticut Museum of Mining and Mineral Science, a large silica mill at Lover's Leap in New Milford was in operation in the late 1880's to about 1920. The quartz from the mine went to this mill or another at Roxbury Falls in the adjacent Roxbury quadrangle. Other outcrop-scale quartz veins generally measure 1- to 2-m-thick and are shown by strike and dip symbols; smaller quartz veins are ubiquitous and have not been mapped separately.

GEOCHEMISTRY

Seven samples of granitic rock were analyzed for major, trace, and rare-earth element geochemistry (table 1). The seven samples correspond to the dated basement gneisses and the Ordovician granites reported in Walsh and others (in press). Major element data indicate that the dated rocks have the composition of peraluminous calc-alkaline granite to quartz monzonite (figs. 3 and 4). All the rocks except Ybgg (sample NM628) have the composition of granite. The Ybgg sample is a quartz monzonite according to the classification of O'Connor (1965) (fig. 4). Chondrite normalized rare earth elements show relatively enriched LREE patterns, and a wide range of concentration (fig. 5). Sample NM174 from the pink granite gneiss (Ygg) shows a pronounced negative Eu anomaly (fig. 5). Samples from the approximately 1.05 Ga Mesoproterozoic rocks (Yag, Ybg, and Ybgg) have virtually indentical patterns (fig. 5) suggesting a similar source. Multi-element or spider diagram patterns (fig. 6) show very similar patterns but non-uniform classifications for all the rocks, and resemble patterns from volcanic arc granites or within plate granites (Pearce and others, 1984). Tectonic discrimination diagrams of Pearce and others (1984) are of limited use (fig. 7) because the samples are not defined consistently by the diagrams. The discrimination diagrams in figure 7 are presented as a preliminary assessment of the possible tectonic setting, and the overlap of the data in the different tectonic fields may be a function of the limited number of samples, the unknown extent of inherited trace elements from the parent rocks, and element mobility in these polymetamorphic rocks.



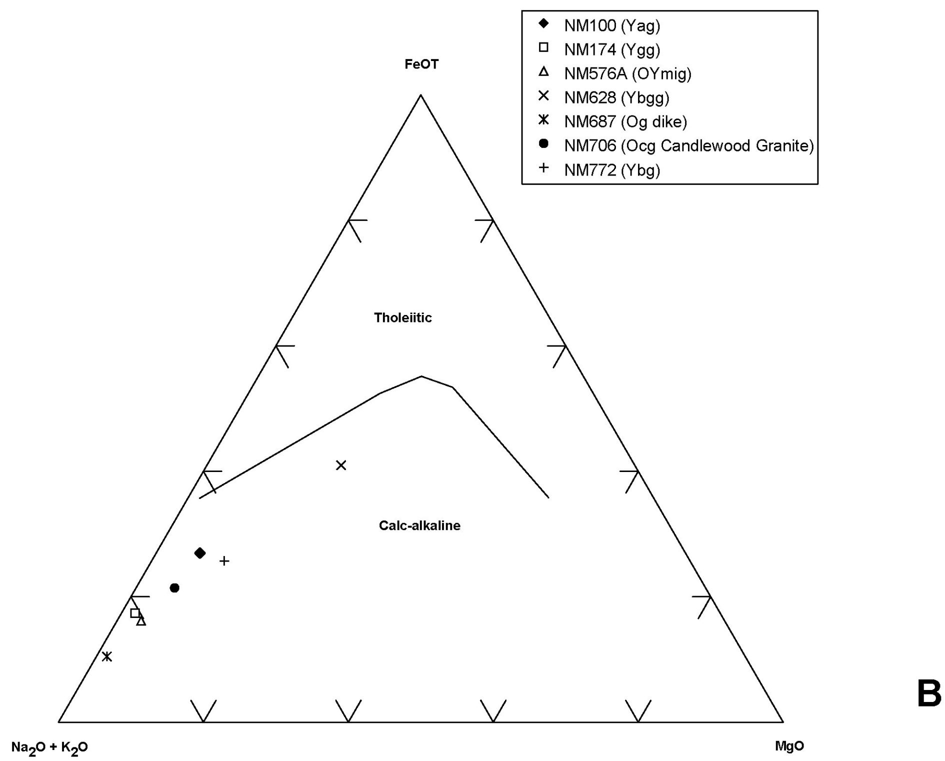


Figure 3. Geochemical discrimination diagrams for the granitic rocks from the New Milford quadrangle. (A) Alumina saturation diagram after Shand (1951) and Maniar and Piccoli (1989); (B) $Na_20 + K_2O$ – FeOT – MgO (AFM) diagram after Irvine and Baragar (1971).

Table 1. Major and trace-element geochemistry of rocks from the 7.5-minute New Milford quadrangle, Connecticut.

Sample No.	NM100	NM174	NM576A	NM628	NM687	NM706	NM772
Map Unit	Yag	Ygg	OYmig	Ybgg	Og dike	Ocg	Ybg
Major elements (%)							
Loss on ignition	0.19	0.40	0.59	0.24	0.70	0.60	0.30
SiO_2	67.7	75.8	72.5	59.7	74.5	72.1	69.9
Al_2O_3	15.2	12.2	14.1	15.2	14.7	14.2	13.8
$Fe_2O_3^T$	3.75	1.73	1.65	7.88	0.84	2.29	3.56
CaO	1.70	0.61	0.99	3.30	1.03	1.61	1.47
MgO	0.61	0.18	0.30	1.96	<0.10	0.47	1.02
MnO	0.05	0.02	0.01	0.09	0.03	0.03	0.04
K_2O	5.84	5.33	5.11	4.54	3.44	4.81	5.76
Na_2O	3.48	2.81	3.25	3.25	3.68	3.1	3.04
TiO_2	0.67	0.23	0.28	1.91	0.08	0.31	0.77
P_2O_5	0.25	0.09	0.14	0.78	0.1	0.15	0.29
Total	99.44	99.40	98.92	98.85	99.10	99.67	99.95
Trace elements by INAA (ppm or %)							
Fe %	2.64	1.23	1.11	5.55	0.57	1.61	2.36
Ca %	1.52	0.55	0.76	2.36	0.61	1.19	1.26
Na %	2.52	2.19	2.53	2.25	2.85	2.36	2.14
K %	4.54	3.99	4.20	4.02	2.76	3.90	4.25
Rb	125.0	93.2	94.3	78.3	132.0	144.0	94.5
Sr	601	107	403	673	177	222	847
Cs	0.13	0.43	0.45	0.17	2.07	1.75	0.28
Ba	2160	676	1250	2180	655	993	1800
Th	22.00	6.48	9.66	3.28	9.64	28.40	26.30
U	1.85	1.18	0.73	1.24	2.57	2.71	1.06
Zr	498	250	165	759	78	243	418
Hf	12.70	7.55	5.47	17.20	3.11	6.62	11.00
Ta	1.54	0.34	0.10	1.45	1.56	0.54	0.89
W	0.276*	0.0547*	0.0713*	0.934*	0.62	0.162*	0.229*
Sc	5.63	2.79	2.08	13.30	2.70	3.05	2.76
Cr	2.18	1.15	2.03	12.10	0.65	4.29	8.90
Co	4.84	1.42	2.02	13.60	0.34	2.84	5.68
Ni	0.39*	2.90	4.40	22.30	2.7*	4.21**	7.55**
Zn	68.00	20.00	28.10	127.00	24.00	44.70	50.20
As	0.16	0.25	0.63	1.89	0.34	0.19	0.11
Sb	0.05	0.02	0.04	0.06	0.07	0.05	0.05
Au (ppb)	0.124*	0.292*	0.1+	0.985*	0.482*	0.1+	0.06*

^{T} Total iron as Fe_2O_3
* interference correction exceeds 60%
** coefficient of variation exceeds 30%
+ below empirical detection limit

Trace elements by ICP40 (ppm)	NM100	NM174	NM576A	NM628	NM687	NM706	NM772
Ag	<2	<2	<2	<2	<2	<2	<2
Be	3	1	2	2	4	2	2
Bi	<10	<10	<10	<10	<10	<10	<10
Cd	<2	<2	<2	<2	<2	<2	<2
Cu	3	3	14	2	5	<1	8
Ga	28	17	23	23	22	22	22
Li	7	6	11	15	2	45	6
Mo	<2	<2	<2	<2	<2	<2	<2
Nb	74	39	39	68	57	50	19
Pb	28	10	28	14	47	19	12
Sn	<5	<5	6	<5	<5	<5	<5
V	24	7	11	79	<2	17	31
Y	38	12	3	48	7	12	16
Rare Earth Elements by INAA (ppm)							
La	99.90	27.00	14.60	105.00	8.70	72.50	103.00
Ce	252.00	65.30	64.30	225.00	24.20	133.00	248.00
Nd	89.80	24.10	10.90	113.00	7.00	49.70	65.90
Sm	15.10	4.62	2.09	19.10	1.91	8.22	9.26
Eu	2.86	0.44	0.62	4.39	0.46	1.32	2.03
Gd	11.50	4.43	1.52	14.20	1.83	6.47	7.22
Tb	1.47	0.56	0.16	1.70	0.28	0.63	0.68
Ho	1.47	0.77	0.14	1.71	0.34	0.49	0.64
Tm	0.54	0.30	0.05	0.59	0.12	0.16	0.23
Yb	3.11	1.76	0.26	3.56	0.76	0.93	1.29
Lu	0.40	0.25	0.04	0.51	0.11	0.13	0.17

Major element analyses by WDXRF of lithium tetraborate fused beads. Analyst D.F. Siems, USGS, Denver, Colorado, USA. Trace element and REE analyses by INAA and ICP40. Analyst J.R. Budahn, USGS, Denver, Colorado, USA. Methods and error limits described in Taggart (2002).

Table 1. (continued)

Sample No.	NM100	NM174	NM576A	NM628	NM687	NM706	NM772
Map Unit	Yag	Ygg	OYmig	Ybgg	Og dike	Ocg	Ybg
CIPW norms (weight percent)							
Q	19.1	36.7	30.9	11.4	37.3	30.5	24.3
or	34.5	31.5	30.2	26.8	20.3	28.4	34.0
ab	29.4	23.8	27.5	27.5	31.1	26.2	25.7
an	7.0	2.5	4.1	11.8	4.5	7.1	5.6
C	0.6	0.9	1.7	0.6	3.3	1.3	0.5
hy	1.6	0.5	0.8	5.0	0.3	1.2	2.6
fs	4.6	2.3	2.0	8.9	1.2	3.0	4.2
mt	0.7	0.3	0.3	1.5	0.2	0.4	0.7
il	1.3	0.4	0.5	3.6	0.2	0.6	1.5
ap	0.5	0.2	0.3	1.7	0.2	0.3	0.6
Total	99.3	99.1	98.3	98.8	98.6	99.0	99.7

CIPW norms calculated with Easy Norm v. 1.0 (http://web.tiscali.it/no-redirect-tiscali/geoware).

Description of sample locations:

NM100 - Danbury augen granite (Yag) - 41° 30' 27.5" N, 73° 29' 41.8" W (Roadcut opposite 6 Laurelwood Drive in New Fairfield.)

NM174 - Pink granite gneiss (Ygg) - 41° 37' 00.2" N, 73° 24' 25.3" W (Outcrop on the west bank of the Aspetuck River, east of Paper Mill Road in New Milford.)

NM576A – Pink granite phase of migmatite (OYmig) - 41° 33' 20.7" N, 73° 27' 52.4" W (Outcrop at Lot 4 Eagle's Nest Road in Sherman.)

NM628 - Biotite granitic gneiss (Ybgg) - 41° 35' 30.6" N, 73° 25' 29.4" W (Roadcut on the driveway to Beacon Reel Company, off Aspetuck Ridge Road in New Milford.)

NM687 - Granite dike (Og) - 41° 33' 36.1" N, 73° 23' 49.8" W (Roadcut of Brookfield Gneiss on Meredith Lane in New Milford.)

NM706 - Candlewood Granite (Ocg) - 41° 36' 39.4" N, 73° 27' 57.8" W (Roadcut at 3 Elena Drive in New Milford.)

NM772 - Layered biotite gneiss (Ybg) - 41° 37' 09.2" N, 73° 26' 23.6" W (Outcrop under power line on the west side of Long Mountain, east of Long Mountain Road in New Milford.)

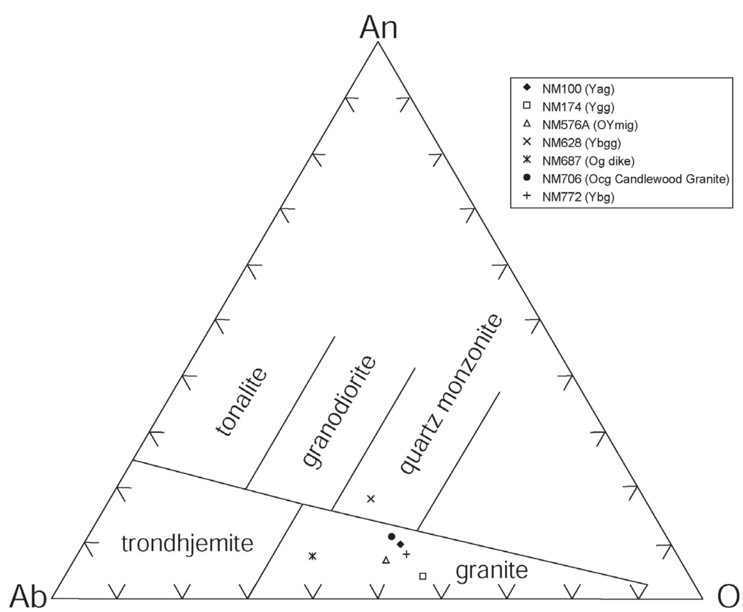


Figure 4. Normative An-Ab-Or classification diagram of O'Connor (1965) showing samples from the New Milford quadrangle.

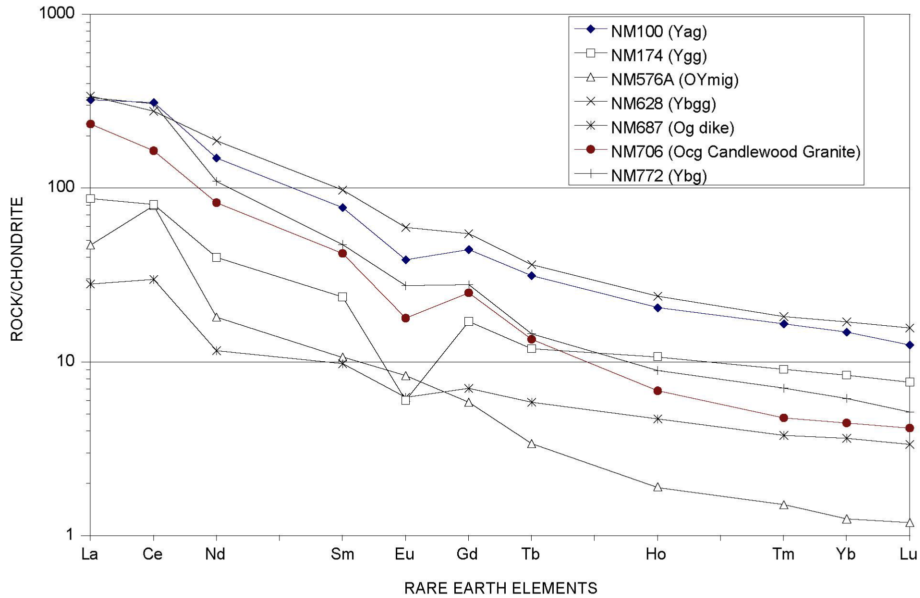


Figure 5. Chondrite-normalized rare earth element diagram showing samples from the New Milford quadrangle.

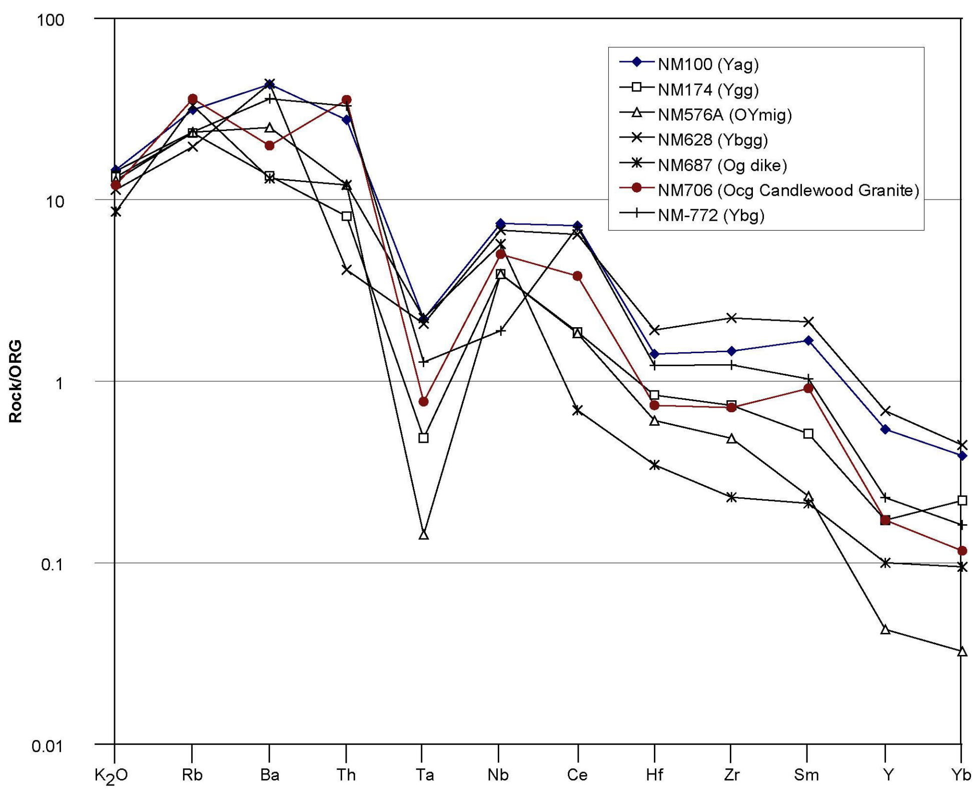


Figure 6. Ocean-ridge granite (ORG) normalized multi-element diagram showing samples from the New Milford quadrangle, after Pearce and others (1984).

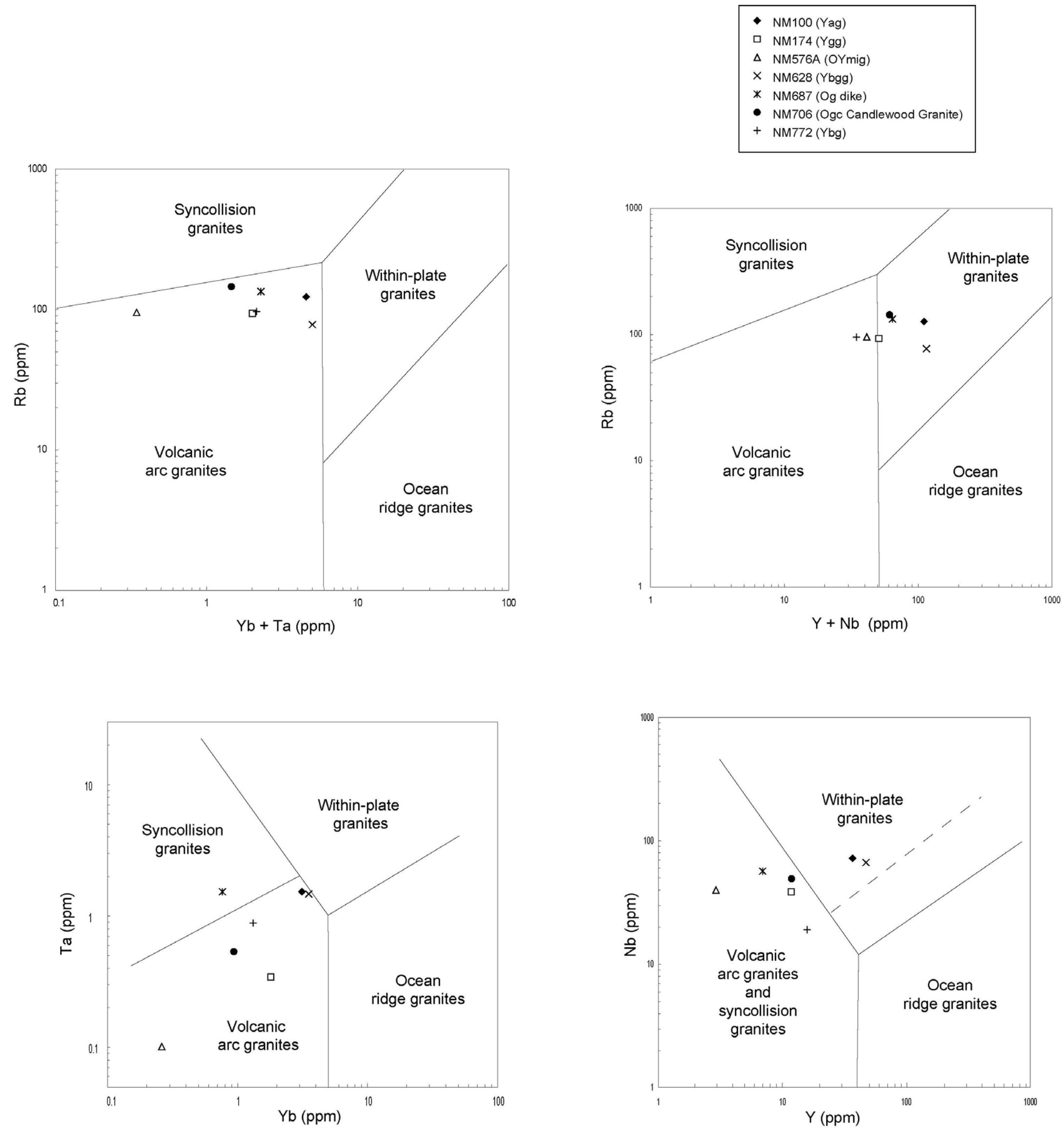


Figure 7. Tectonic discrimination diagrams showing samples from the New Milford quadrangle, after Pearce and others (1984).

STRUCTURAL GEOLOGY

Ductile Structures

At least five generations of ductile deformation are recorded in the rocks of the New Milford quadrangle. The two oldest generations are Mesoproterozoic and are designated YD1 and YD2. Three generations of Paleozoic deformation occur in the Neoproterozoic to Lower Paleozoic rocks and are designated D1, D2, and D3.

Mesoproterozoic

The oldest foliation in the area is a cryptic, layer-parallel gneissosity (YS1) that rarely was observed in all the Mesoproterozoic rocks except the Danbury augen granite (Yag) where it was never seen. In all observed instances, the YS1 gneissosity is a relict foliation preserved in the hinges of isoclinal folds (fig. 8). No measurements of YS1 were made because the folded foliation is always transposed and reoriented into the plane of the younger Mesoproterozoic deformational fabric (YS2) (fig. 8). Folds associated with the oldest fabric were not observed anywhere in the quadrangle, perhaps because of the penetrativeness of the younger deformational fabrics and not because they never existed. This oldest period of deformation (YD1) predates the intrusion of the Danbury augen granite (Yag) because YD1 fabrics are not present within the pluton. The YD1 deformation, therefore, is pre c. 1.05 Ga and pre-Ottawan. The oldest dated rock in the quadrangle, the pink granite gneiss (Ygg, 1311 ± 7 Ma, Walsh and others, in press), contains the YS1 fabric, suggesting that the YD1 deformation is post c. 1.3 Ga and is perhaps Elzevirian as defined by Rivers (1997).

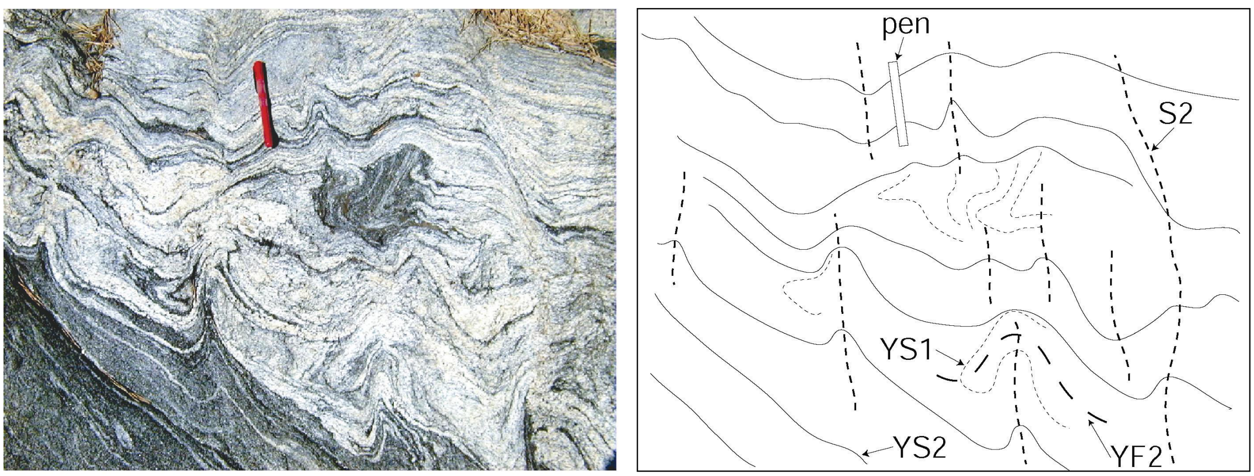


Figure 8. Map view photograph and sketch of the migmatite gneiss (OYmig) showing foliations within the gneiss. The lighter material is granitic leucosome within the migmatite and the darker material is amphibolite and biotite-rich gneiss that is typical of rocks within the layered biotite gneiss unit Ybg. The lighter material resembles the dated Mesoproterozoic migmatite gneiss (sample NM576B), collected from the same outcrop approximately 10 m south of the photograph. Relict Mesoproterozoic foliation YS1 is preserved in second-generation Mesoproterozoic rootless folds (YF2) whose axial surfaces are largely parallel to the dominant Mesoproterozoic gneissosity in the area (YS2). Second-generation Paleozoic deformational features include upright folds (F2) and associated cleavage (S2) that warp the Mesoproterozoic fabrics. North is up. Pen for scale, 15 cm. Photograph taken at sample site NM576 on Eagle's Nest Road north of Green Pond in Sherman.

The second-generation foliation in the Mesoproterozoic basement rocks is a penetrative gneissosity (YS2) that is the dominant planar fabric in all the basement rocks (fig. 8). The YD2 event deformed the YS1 foliation into isoclinal folds (YF2) (fig. 8). Symbols of the Mesoproterozoic folds and gneissosity shown on Plate 1 correspond to the YF2 and YS2 fabrics. These YD2 structures experienced significant Paleozoic overprint in most of the area to the extent that the YS2 gneissosity is generally parallel to the dominant fabric in the cover rocks (S2) (figs. 9 and 10). In general, the YS2 gneissosity strikes north-south and dips steeply to the west. The average strike and dip of the YS2 gneissosity is 185°, 77° (fig. 9). Measurable YF2 fold axes, although rare, generally plunge steeply down the dip of the YS2 gneissosity (fig. 9). Definitive Mesoproterozoic mineral lineations were not observed in the area. Within the Danbury augen granite, the YS2 foliation is recognized as a variably penetrative gneissosity that wraps around microcline megacrysts. The foliation in the Danbury Augen granite has the same relative age as the dominant foliation within the surrounding host rocks (Ybg, Ymig, and Yhg) in the southwestern part of the map. This second phase of Mesoproterozoic deformation (YD2) is attributed to the Ottawan Orogeny (Walsh and others, in press).

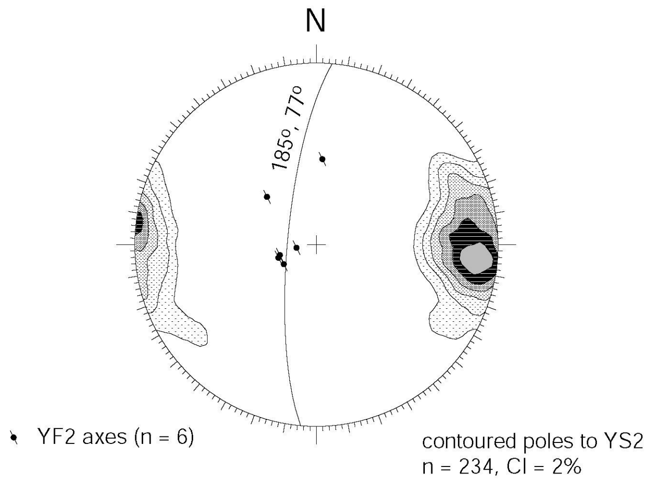


Figure 9. Lower hemisphere equal-area projection of contoured poles of the Mesoproterozoic YS2 gneissosity showing YF2 fold axes. The strike and dip of the average plane is 185°, 77°. North is marked by "N", the number of points in the dataset is indicated by "n", and the contour interval (CI) is 2 percent. Data are plotted with the Structural Data Integrated System Analyzer software (DAISY 3.41) by Salvini (2002).

Paleozoic

The oldest Paleozoic foliation is a cryptic layer-parallel schistosity (S1) that rarely was observed in the cover rocks and not seen in the basement rocks. In the Manhattan, Rowe, and Ratlum Mountain Schists, the S1 schistosity is locally preserved in the hinges of younger folds or it may be the dominant schistosity. Outcrop-scale refolded isoclinal F1 folds occur in these lithotectonic sequences, but their occurrence is not widespread. Where the F1 folds are preserved, the S1 schistosity is axial planar to the folds which deform the bedding in the rocks. In the autochthonous rocks, the S1 schistosity is also locally preserved in the hinges of younger folds, but no evidence of F1 folds was observed at either the outcrop or map scale. Detailed mapping and tracing of beds of calcite marble layers in the Walloomsac Formation, in fact, appears to preclude F1 folds in these rocks. The lack of F1 folds in the autochthonous rocks suggests that the Paleozoic D1 deformation varied in intensity between the autochthonous rocks and the allochthonous rocks, and that the rocks that experienced greater movement also experienced greater deformation prior to their arrival at their current location. Plotted poles to S1 (fig. 10) show loosely defined best-fit great circles whose π poles generally match the trend of the second-generation Paleozoic fold axes (F2). The first phase of Paleozoic deformation (D1) is attributed to the early stages of the Taconian Orogeny, during the Ordovician, and it must have occurred after the deposition of the Walloomsac Formation but before the intrusion of the

Brookfield Gneiss. The D1 deformation phase is also associated with the transport of the thrust slices in the area, because the slices are deformed by the younger D2 structures.

The second-generation Paleozoic foliation is a penetrative schistosity (S2) that is commonly the dominant planar fabric in all the cover rocks. The S2 foliation in the basement rocks varies from a non-penetrative cleavage (fig. 8) to a penetrative mylonitic schistosity along the east side of the New Milford massif, near the Fort Mountain fault. The S2 foliation deforms the S1 foliation into reclined isoclinal folds (F2) whose fold axes plunge, on average, to the west-northwest (fig. 10). F2 fold axes show a wide range in orientation throughout the area, and locally outcrop scale F2 folds are doubly plunging with moderate plunges to both the north and south. The major map-scale folds shown on Plate 1 are interpreted as large F2 doubly plunging antiforms and synforms. Second-generation Paleozoic mineral lineations (L2) defined by hornblende, k-feldspar, biotite, quartz, stretched pebbles, and elongated microcline augen plunge, on average, steeply down dip to the west (fig. 11). The L2 lineations are best developed in the eastern part of the map, where they show a change in orientation from west-southwest near the Fort Mountain fault, west-northwest near Cameron's Line, and northwest east of the Brookfield Gneiss (fig. 11). The difference in L2 orientations is either the result of a change in the elongation direction across the area during D2 deformation and metamorphism or a change in the orientation of older reference surfaces such as steeply dipping S1 in the cover or YS2 in the basement. On average, the S2 schistosity strikes north-south and dips steeply to the west (fig. 10). Across the map, however, the strike of the S2 schistosity changes slightly from northwest in the southern part of the map to northeast in the northern part of the map (Plate 1). The D2 deformation phase is attributed to the peak deformational phase of the Taconian Orogeny. The timing of D2 is partly constrained by the ages of the syn-tectonic Ordovician intrusions including the Candlewood Granite (443 ± 7 Ma), the migmatitic leucosomes in the Mesoproterozoic migmatite gneiss (444 ± 6 Ma), the leucogranite dike in the Brookfield Gneiss (453 ± 6 Ma) (Walsh and others, in press), the Brookfield Gneiss (451 ± 1) (Sevigny and Hanson, 1995). These ages suggest that D2 developed, at least in part, during the period from 453 to 443 Ma.

The third-generation Paleozoic foliation is a widespread, non-penetrative cleavage (S3) that has a variable orientation across the map. On average, the S3 cleavage generally strikes northeast and dips moderately to the northwest (fig. 10), but locally the strike and dip may vary considerably because the folds are often box style or conjugate folds. Folds associated with the third-generation fabric (F3) are open to tight and plunge moderately to the north (figs. 10 and 12). Regionally this deformation event (D3) is associated with Acadian pre- to syn-dome-stage folding that increases towards the east, outside the New Milford quadrangle (Gates, 1959; Stanley, 1975; Stanley and Caldwell, 1976; Rodgers, 1985; Chocyk-Jaminski and Dietsch, 2002). These structures may correlate with the Acadian D4 or D5 folds farther to the north and west (Ratcliffe and Harwood, 1975; Hatch and Stanley, 1976; 1988). No map-scale dome-stage folds are present in the New Milford area.

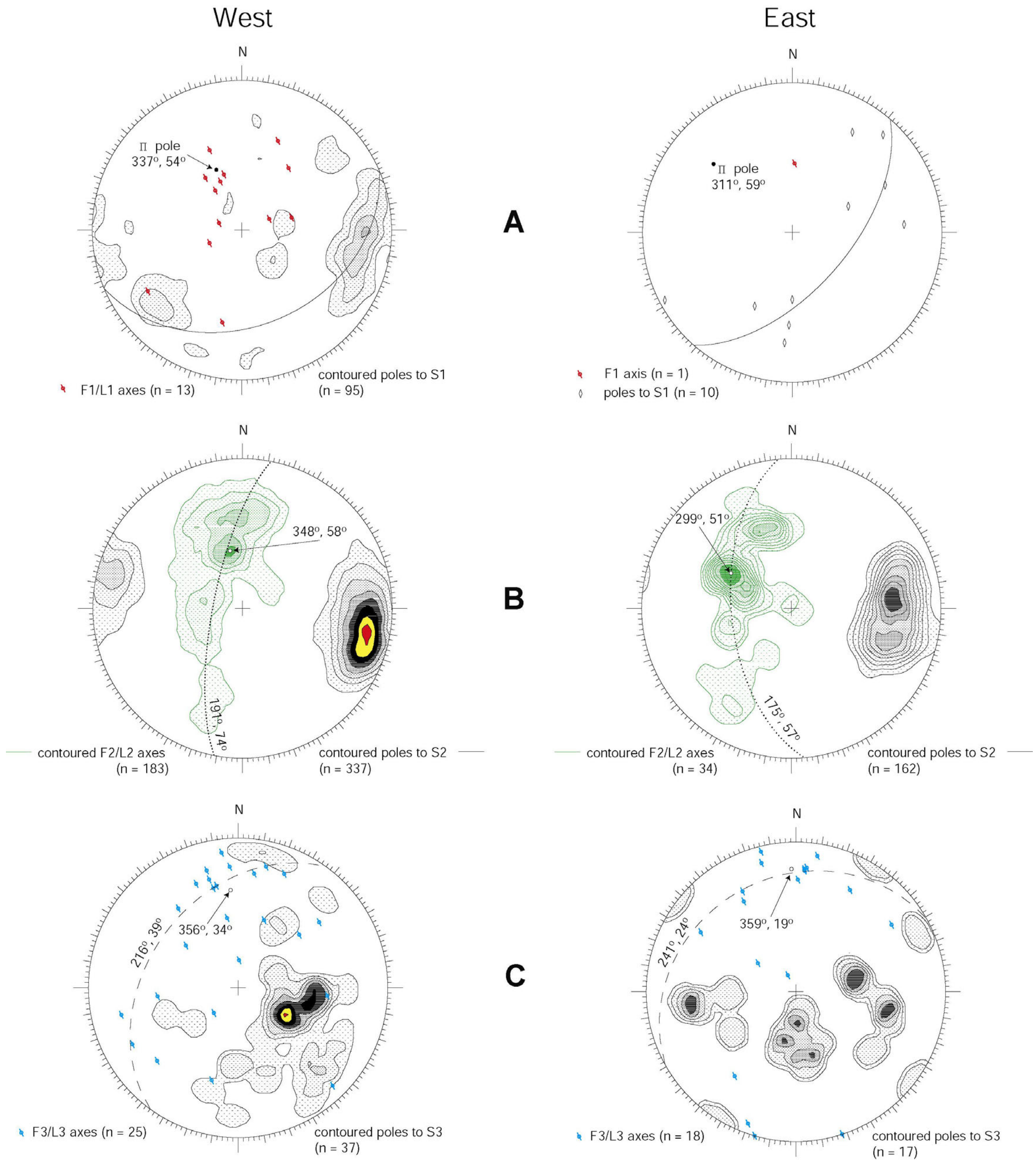


Figure 10. Lower hemisphere equal area projections of three generations of Paleozoic structures from the New Milford quadrangle. Data are separated into domains "West" and "East" of Cameron's Line. (A) The top two diagrams show poles to S1 (contoured in West and not contoured in East), F1 fold axes and L1 intersection lineations, best-fit great circles to poles, and π poles to best-fit great circles. (B) The middle two diagrams show contoured poles to S2 in black and contoured poles to F2 fold axes and L2 intersections lineations in green. The strike and dip of the average S2 planes is indicated by the dotted great circles, and the point maxima for the linear data are indicated by arrows. (C) The bottom two diagrams show contoured poles to S3 and F3 fold axes and L3 intersection lineations. The strike and dip of the average S3 planes is indicated by the dashed great circles. In all diagrams, north is marked by "N", the number of points in the dataset is indicated by "n", and the contour interval, where applicable, is 2 percent. Data are plotted with the Structural Data Integrated System Analyzer software (DAISY 3.41) by Salvini (2002).

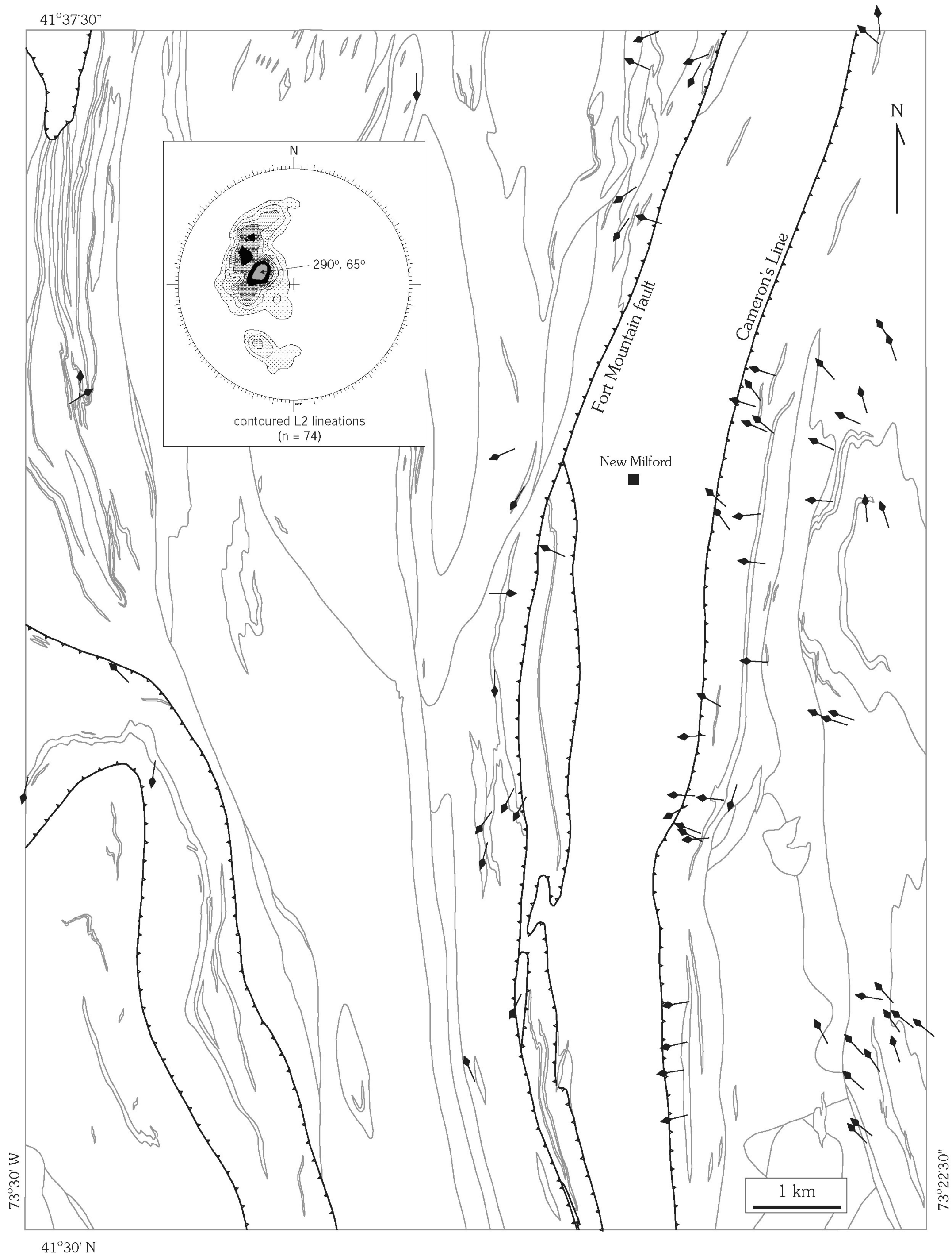


Figure 11. Summary map of L2 mineral lineation trends in the New Milford quadrangle. Lineations are defined by hornblende, k-feldspar, biotite, quartz, stretched pebbles, and elongated microcline augen. Inset diagram shows a lower hemisphere equal area projection of contoured lineations. The point maximum is oriented at 290°, 65°. On the stereonet, north is marked by "N", the number of points in the dataset is indicated by "n", and the contour interval is 2 percent. Bearing and plunge of lineations is also shown on Plate 1. Geologic contacts from Plate 1 are shown in gray.

Figure 12. Outcrop of Ratlum Mountain biotite schist (OCr) showing a late west dipping F3 fold that deforms the dominant schistosity (S2). Photograph is from an outcrop at the bottom of Hine Hill Road, just east of the Housatonic River in New Milford. View is to the north, west is to the left. Hammer for scale, 33 cm long.

Prior to the mapping of the New Milford quadrangle, the work in the Kent quadrangle (Jackson, 1980) and in the Newtown quadrangle (Stanley, 1975; Stanley and Caldwell, 1976) represented the most detailed structural analysis in the area. The Paleozoic structures reported by Jackson, Stanley, and Caldwell closely match the style, orientation, and relative ages seen in the New Milford quadrangle. Jackson (1980, p. 47) did not use the terms D1, D2, and D3 but used “Early Isoclinal Stage”, “Bear Hill Stage”, and “Late Stage”, respectively, to describe the correlative structural events. Stanley (1975) and Stanley and Caldwell (1976) used the terms F1, F2, and F3 to describe these structures. Evidence in both quadrangles suggested to the authors that the D1/F1 event was Taconian, and that subsequent deformation was Acadian. Stanley interpreted the F2 folds as Acadian because he believed the D2 fabrics could be traced eastward into the Silurian and Devonian Straits Schist (Hatch and Stanley, 1973; Stanley, 1975; Stanley and Caldwell, 1976). The ages of syn-tectonic D2 intrusions in this quadrangle range from 453 to 443 Ma indicating that the D2 deformation event occurred during the Ordovician not the Devonian. I cannot rule out the possibility, however, that the D2 fabrics developed diachronously and continued to tighten well after the intrusion of the Ordovician igneous rocks.

Ductile Faults

Two generations of ductile faults are present within the New Milford quadrangle -- pre-peak metamorphic and syn-metamorphic.

Pre-peak metamorphic faults occur along the base of the Edmonds Road, Briggs Hill, and Fort Hill slices of the Manhattan Schist and are possibly related to early motion along Cameron's Line. These faults are generally parallel to the S1 schistosity in the cover rocks and developed during the D1 deformation event, prior to peak Paleozoic metamorphic conditions. The faults are deformed by the younger Paleozoic D2 and D3 fabrics. Truncations of units along the faults are largely inferred from map patterns of marker horizons such as the Walloomsac Formation calcite marble (Owm) in the lower plate or Manhattan Schist amphibolite (CZma) in the upper plate. The best evidence of lower plate truncations occurs at the southern end of the Edmonds Road slice, where calcite marble horizons in the Walloomsac Formation trace into the contact with the overlying Manhattan Schist (CZm). Thin continuous horizons of amphibolite in the Manhattan Schist occur along the length of the Fort Hill slice, but their truncation is inferred. Near the southern extent of the Fort Hill slice in the New Milford quadrangle, several isolated belts of Dalton Formation (CZd) crop out on both sides of the Manhattan Schist, and the map pattern suggests lower plate truncation of the contact between the Dalton Formation and Manhattan Schist.

Mylonitic fabric is present in the rocks near Cameron's Line and the Fort Mountain fault, and this fabric is parallel to the dominant S2 foliation in the rocks. For this reason Cameron's Line in the New Milford quadrangle is considered largely synchronous with D2. The fault is not exposed in the map area. Elsewhere in Connecticut, others consider Cameron's Line either a pre-peak metamorphic fault (Hall, 1980; Panish and Hall, 1985; Spinek and Hall, 1985; Rodgers, 1985) or a syn-metamorphic D2 fault (Merguerian, 1987). The closest outcrops between the Stockbridge Formation to the west and the Ratlum Mountain Schist to the east are hundreds of meters apart, so details about the fault are unknown here. The westward dip of Cameron's Line and the dominant foliation has been associated with younger Acadian folding (Rodgers, 1985; Panish, 1992; Merguerian, 1987; Sevigny and Hanson, 1995), thus Cameron's Line originally dipped to the east prior to D3. Most consider early east-over-west motion along Cameron's Line as the major tectonic activity associated with the fault (Hall, 1980; Panish and Hall, 1985; Spinek and Hall, 1985; Rodgers, 1985; Merguerian, 1987). Whether the transport occurred during D1 or D2, or both, is not entirely clear in this area, because of poor exposure, but the fabric near the fault suggests significant deformation during D2. Later west-over-east motion (D3 or younger) on Cameron's Line cannot be ruled out, but this appears less likely as the fabric along the fault is predominantly D2 in age.

The Fort Mountain fault is named for the D2 mylonitic fabric that occurs along the entire length of the fault from Gallows Hill northward to the east side of Fort Mountain, and then to the east side of Mount Tom. Penetrative mylonitic fabric is most evident in the belts of Danbury augen granite along Fort Mountain. Motion sense along the fault is unknown, but may have originally been east-over-west, presumably when the fault dipped to the east before D3 folding and doming.

Brittle Structures

The brittle structures in the area include faults, joints, and joint sets (Plate 2). The orientation of joints and joint sets measured in this study include those with trace lengths greater than 20 cm (Barton and others, 1993). Joints and joint sets were measured subjectively (Spencer and Kozak, 1976; Walsh and Clark, 2000), and the data set includes the most conspicuous joints and joint sets in a given observed outcrop. Joint and joint set data are plotted on rose diagrams (azimuth-frequency) and stereonets (lower hemisphere equal area projections) using the Structural Data Integrated System Analyzer software (DAISY 3.41) by Salvini (2002). The DAISY software uses a Gaussian curve-fitting routine for determining peaks in directional data (Salvini and others, 1999) that was first described by Wise and others (1985). The rose diagrams include strike data for steeply dipping fractures (dips > 60°, after Mabee and others, 1994).

Faults

Twenty-one minor outcrop-scale faults were observed in the area (Plates 1 and 2, fig. 13). All the faults were identified from slickensided surfaces. Offset was visible only along one fault where displacement measured 5 cm. Of the 21 faults, ten show normal, seven show left lateral, and four show reverse relative motion (fig. 13). The left-lateral faults strike consistently west-northwest, but the other faults show no preferred orientation (fig. 13). Wise (1981, p. ix) noted the presence of “a pattern of more abundant NW trending left lateral faults” within a north-northeast trending 50 km wide zone across western Connecticut and Massachusetts that he considered to be a continuation of the Newark Basin – Ramapo fault system. Analysis of fault slip data using a linear least squares method (Reches, 1987) in the DAISY software package (Salvini, 2002) suggests that the faults represent a heterogeneous data set because the calculated angular divergence (θ) between predicted slip and actual slip directions exceeds 20° (Hardcastle, 1989) for all but four of the faults. The heterogeneous nature of the fault data is expected for rocks with significant planar anisotropy, such as the well-foliated rocks in this study, because faults may develop at angles up to 60° from σ1 in such rocks (Donath, 1961).

Joints and Joint Sets

Spacing of joint sets ranges from 5 cm to 1.5 m with an average of 31 cm. The connectivity of the joints and joint sets is expressed as a percentage of blind, crossing, and abutting fractures after Barton and others (1993). The connectivity ratio in the data set is 76 percent blind, 6 percent crossing, and 18 percent abutting, suggesting limited interconnectivity. The termination ratio is not representative of the entire data set, however, as it only includes joints where the termination could be unequivocally determined. In addition to recording joint termination, throughgoing joints that transect rather than terminate within the outcrop were recorded. Blind and abutting joints cannot be throughgoing, but crossing joints can be. Not all throughgoing joints are necessarily crossing, however, because if the throughgoing joint does not come in contact with other joints in the outcrop, the termination relationships with other joints is not known. All measured joint sets are throughgoing, but only 57 percent of the measured joints are throughgoing (fig. 14).

The majority of the joints and joint sets observed in the area are steeply dipping, but gently dipping fractures or sheeting joints are also present, as shown in the stereonets (fig. 14). Joint and joint set orientations for the entire quadrangle show a dominant northwest-striking, steeply dipping trend (fig. 14). The peak joint trend for steeply dipping joints (dip > 60°) is 284 ± 6° (fig. 14A). The peak joint set trend for steeply dipping joint sets is 295° ± 6° (fig. 14B). Contoured poles to joints show that the gently dipping sheeting joints have a point maximum at 12°, 11° indicating a preferred gentle dip to the east (fig. 14A). Since most of the sheeting joints are non-throughgoing, the point maximum shows up best on the non-throughgoing stereonet (fig. 14C). Joint trends for the entire dataset appear to be dominated by the subset of throughgoing joint trends, as the directional plots are quite similar (figs. 14A & D). Non-throughgoing joint trends show a preferred east-west trend (88° ± 5) (fig. 14C). Wise (1981) reports similar joint trends along a transect (traverse E) that passed through the Danbury quadrangle to the south.

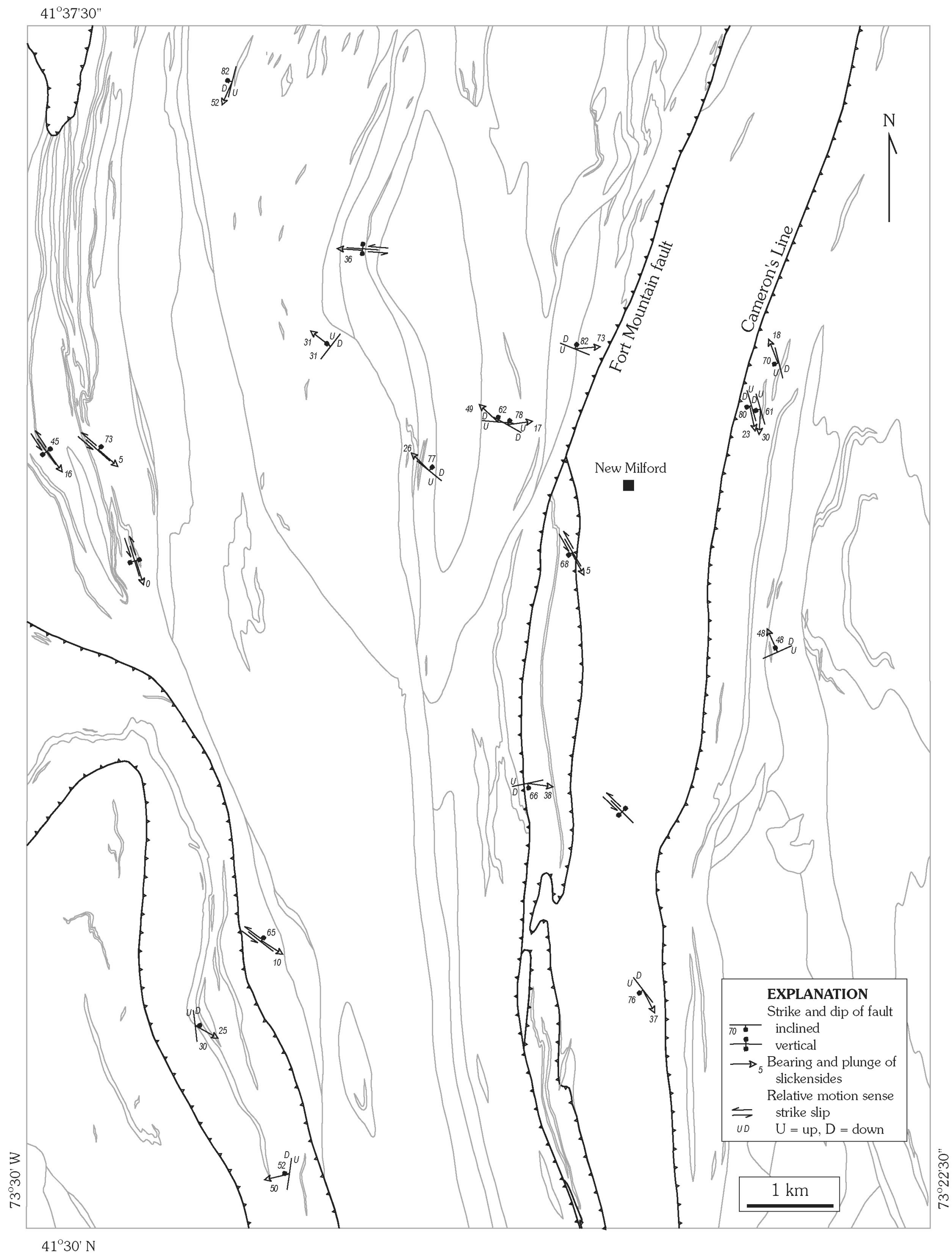


Figure 13. Map of outcrop-scale brittle faults in the New Milford quadrangle. Faults are also shown on Plates 1 and 2. Geologic contacts from Plate 1 are shown in gray.

#	Nor. H.	Azimuth	sd
1	100.0	283.7°	5.6°
2	88.0	88.1°	5.5°
3	62.0	297.0°	6.3°
4	47.4	313.0°	9.0°
5	34.4	57.3°	7.5°
6	39.7	76.7°	6.4°
7	31.0	40.0°	12.1°

#	Nor. H.	Azimuth	sd
1	100.0	295.4°	5.8°
2	65.9	81.6°	5.2°
3	49.7	51.8°	4.6°
4	49.8	276.1°	5.4°
5	40.9	308.1°	4.5°
6	36.5	40.3°	4.0°
7	22.0	72.2°	5.4°

#	Nor. H.	Azimuth	sd
1	100.0	88.1°	5.3°
2	84.3	287.5°	5.1°
3	67.3	47.6°	6.6°
4	52.7	308.8°	6.7°
5	48.9	64.5°	5.0°
6	39.4	278.0°	4.2°
7	34.1	297.0°	3.3°
8	35.2	78.0°	4.1°
9	18.9	325.6°	13.3°
10	22.1	28.9°	5.0°

#	Nor. H.	Azimuth	sd
1	100.0	283.8°	5.3°
2	77.6	88.2°	5.4°
3	63.5	297.4°	6.1°
4	41.3	313.2°	8.5°
5	40.0	76.7°	5.8°
6	33.1	57.6°	7.2°
7	23.4	35.3°	12.4°

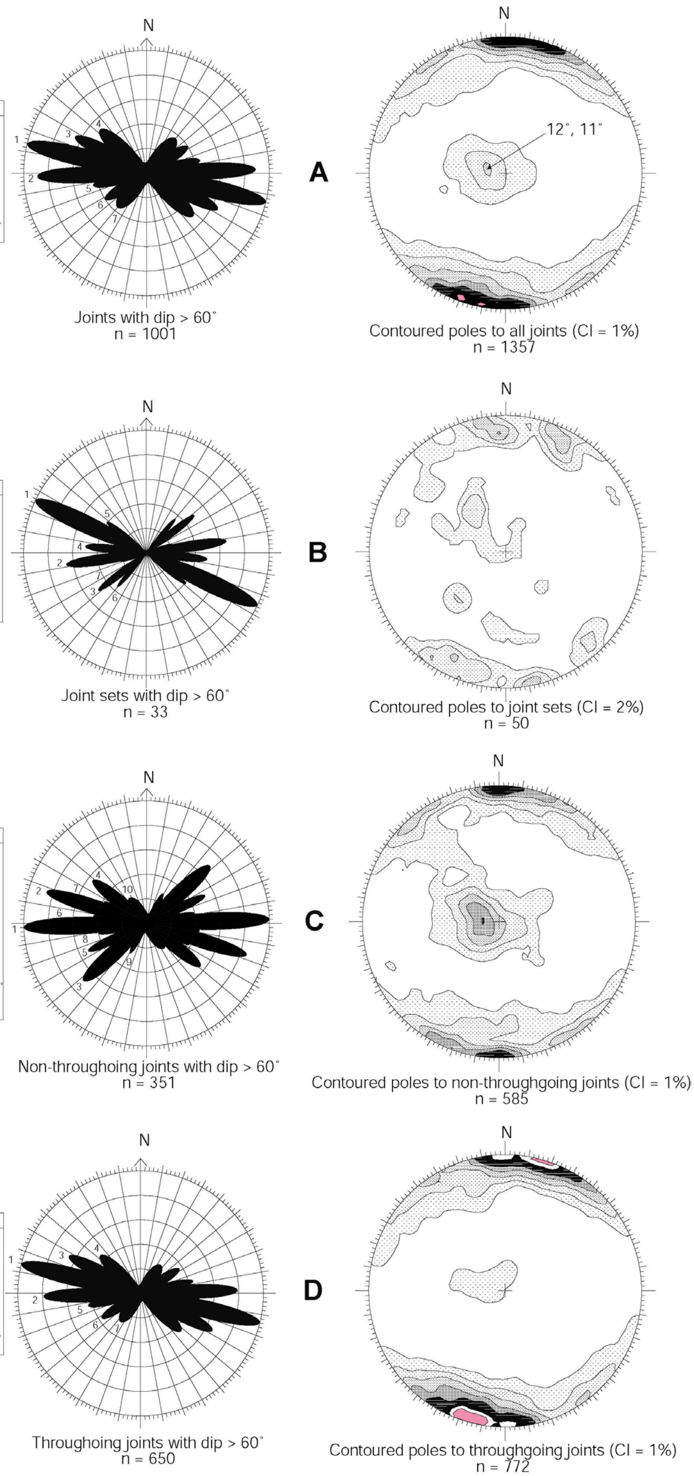


Figure 14. Lower hemisphere equal area projections (stereonets) and normalized azimuth-frequency (rose) diagrams of joints and joints sets in the New Milford quadrangle. A) all joints, B) joint sets C) non-throughgoing joints, and D) throughgoing joints. Rose diagrams include features with dips greater than 60°. In all diagrams, north is marked by "N" and the number of points in the dataset is indicated by "n". The contour interval (CI) in the stereonets is shown in parentheses. Tables to the left of the rose diagrams show joint trends, normalized height (Nor. H.), azimuth, and 1 standard deviation (sd) determined by a Gaussian curve-fitting routine. Data are plotted with the Structural Data Integrated System Analyzer software (DAISY 3.41) by Salvini (2002).

Parting

In an effort to evaluate the control of structures produced by ductile-deformation structures or primary layering on brittle fracture development and orientation in the area, parting data were collected along with structural measurements (Table 2). According to Bates and Jackson (1987, p. 484), parting in structural geology is defined as, "A joint or fissure; specif. a plane or surface along which a rock is readily separated or is naturally divided into layers". In this study, by definition, all joints and brittle faults exhibit parting. Additionally, parting was observed parallel to ductile-deformation features such as schistosity, layer-parallel schistosity, axial surface of folds, cleavage, gneissosity, and along primary bedding. Where these pre-existing structures exhibit parting, they are called "parting fractures" and their symbols are shown not only on the geologic map (Plate 1), but also on the brittle structure map (Plate 2) along with the standard brittle structures such as brittle faults, joints, and joint sets. Parting data are summarized by rock type and map unit in Figure 15 and Table 2. The degree of parting for rock type and map unit is expressed as a percentage of the number of measurements that exhibit parting (excluding joints and brittle faults), divided by the total number of measurements. The parting data by rock type show that quartzite and granite exhibit the greatest degree of parting in the area (fig. 15). Rocks that exhibit less parting are the least layered or least foliated rocks and include the Danbury augen granite, marble, and the Brookfield Gneiss (diorite) (fig. 15).

Fracture Trend Analysis

The fracture trend analysis map on Plate 2 shows the distribution of fracture trends by domain. The north-south trending domain boundaries follow major geologic contacts and faults (fig.1 on Plate 2). The east-west trending boundaries are based on groups of closely spaced outcrops where fracture measurements were collected (fig.1 on Plate 2). The domain boundaries subdivide the spatial data but do not necessarily separate rocks with distinctly different fracture trends (ie. Mabee and Hardcastle, 1997).

Stereonets on the fracture-trend analysis map depict all fracture data within a given domain, and rose diagrams show the azimuthal trends for the steeply dipping subset of fractures. Fracture-trend orientations shown on the rose diagrams show principal trends ranging from the northeast to northwest. A principal fracture trend is defined as having normalized peaks greater than 50 percent of the highest peak (Hardcastle, 1995). On each of the rose diagrams, the trend of parting fractures is shown in red. In all of the plots, the peaks associated with the more numerous non-parting related fractures (joints, joint sets, and faults) dominate the data. A qualitative assessment of the data shows a general orthogonal relationship between the strike of steeply dipping parting fractures and the non-parting fractures. The orientation of this orthogonal relationship changes across the map in relation to the orientation of the pre-existing fabric in the rock, suggesting that anisotropy played a significant role in the development of peak fracture trends in the area. Donath (1961, p. 985) showed experimentally that "planar anisotropy (foliation) may have a marked effect on both the breaking strength and the angle of shear fracture in rocks".

Table 2. Summary of parting fractures by map unit and rock type for the 7.5-minute New Milford quadrangle, Connecticut. Parting fractures were observed parallel to schistosity, layer parallel schistosity, axial surface of folds, cleavage, gneissosity, and bedding. Parting parallel to joints, joint sets, and brittle faults is not included in this table.

Map Unit	Formation	Rock Type	Number of Measurements	Number of Measurements that Exhibit Parting	Percent Parting by Map Unit
CZma	Manhattan Schist	amphibolite	43	5	12
OCra	Ratlum Mtn. Schist	amphibolite	20	9	45
Yhg		amphibolite	21	4	19
Yag	Danbury augen granite	augen granite	56	7	13
Ybg		biotite gneiss	101	23	23
Ybgg		biotite gneiss	8	6	75
Obd	Brookfield Gneiss	diorite	20	2	10
Obqd	Brookfield Gneiss	diorite	20	7	35
Obqm	Brookfield Gneiss	diorite	4	0	0
Ygg		granite gneiss	21	5	24
Og/Ocg		granite	92	33	36
OCs	Stockbridge Fm.	marble	37	10	27
Owm	Walloomsac Fm.	marble	37	3	8
OYmig		migmatite gneiss	100	26	26
Op		pegmatite	3	0	0
CZdq	Dalton Fm.	quartzite	8	6	75
OCrfq	Rowe Schist	quartzite	3	0	0
OCsq	Stockbridge Fm.	quartzite	2	0	0
CZd	Dalton Fm.	schist	67	19	28
CZm	Manhattan Schist	schist	101	16	16
OCr	Ratlum Mtn. Schist	schist	104	38	37
OCrg	Rowe Schist	schist	26	5	19
OCrk	Ratlum Mtn. Schist	schist	2	0	0
Ow	Walloomsac Fm.	schist	83	6	7
Oqv		vein	1	0	0

In an effort to quantify the orthogonal relationship between parting anisotropy and peak fracture trends seen in this quadrangle, the acute angle between the parting fracture trends and peak fracture trends was calculated for each fracture analysis domain (Plate 2). This angle is called the "acute dihedral angle". The peak fracture trend for each domain has a normalized height of 100 percent. The calculated peak acute dihedral angle (82° ± 5°) shown in Figure 2 on Plate 2 is a summary of the statistical peak for all measured individual acute dihedral angles from the 17 domains. The peak acute dihedral angle (PADA) of 82° quantifies the orthogonal relationship seen in the data. A comparison of the calculated PADA versus individual domain peaks seen in the data set shows that the PADA matches the peak fracture trend in all the western and southern domains within 1σ error (± 5°) (Plate 2, fig. 3). All but three of the domains match within 2σ error (± 10°), and all but the two northeastern domains match within 3σ error (± 15°) (Plate 2, fig. 3). In the two northeastern domains (5 & 6), the PADA does not match the peak fracture trend within 15°, but does match principal fracture trends by either 1 or 2σ error. This analysis shows that, in the absence of fracture data, the orthogonal relationship might be used as a preliminary tool for predicting regionally significant fracture trends in metamorphic rocks with steeply dipping, consistently striking penetrative foliation. Stone and others (2002) describe an ongoing project to classify the bedrock geology of Connecticut into rock groups with similar fracture properties, and the results presented here may be useful for such studies. The orthogonal relationship between peak fracture trends and foliation has been observed in other study areas in New England where metamorphic rocks contain steeply dipping consistently striking penetrative foliation or layering (Walsh and Ratcliffe, 1998; Walsh, 1998; Walsh and Clark, 1999; 2000).

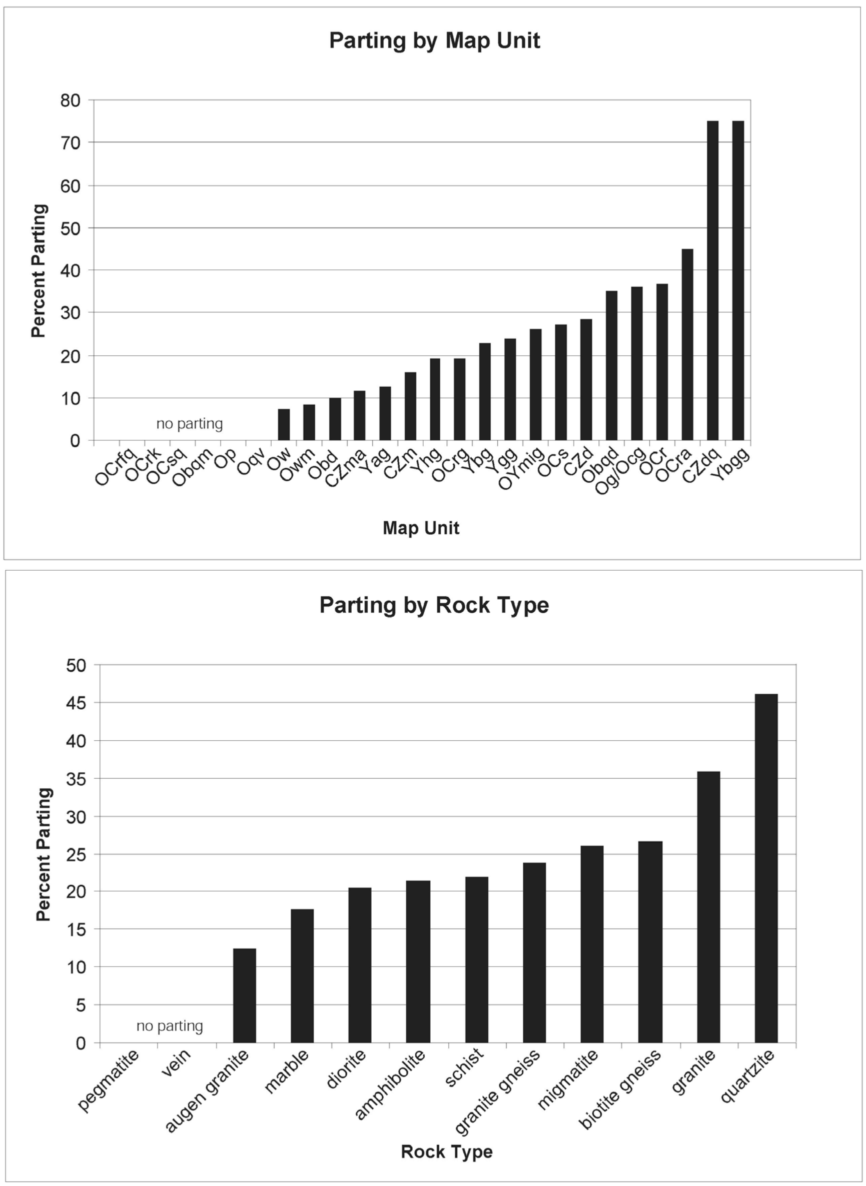


Figure 15. Summary histograms of parting by map unit (top) and by rock type (bottom), expressed as a percentage of foliation or layer-parallel measurements that exhibit fracturing.

METAMORPHISM

The rocks in the New Milford quadrangle are polymetamorphosed. Mesoproterozoic basement consists of upper amphibolite facies gneisses, in agreement with earlier findings for this area (Hall and others, 1975). Mesoproterozoic rocks of the Hudson Highlands and western Connecticut massifs experienced granulite facies and amphibolite facies metamorphism (Hall and others, 1975; Murray, 1976) that was subsequently overprinted during the Ordovician and Devonian (Dallmeyer and others, 1975; Dallmeyer and Sutter, 1976; Dana, 1977; Jackson, 1980; Sutter and others, 1985; Hames and others, 1991). In the New Milford quadrangle, the basement rocks experienced Paleozoic metamorphism that reached upper amphibolite facies, indicated by sillimanite-K-feldspar assemblages in the cover rocks. Both the basement and cover rocks experienced subsequent metamorphism during the Devonian (Hames and others, 1991). A U/Pb ion microprobe age from metamorphic zircon from the hornblende gneiss (sample NM159, Yhg) show that a Grenville metamorphic event in the New Milford massif occurred as late as 993 ± 8 Ma (Walsh and others, in press).

Regional Paleozoic amphibolite facies metamorphism in the area spanned the Taconian and Acadian events (Hames and others, 1991). West of Cameron's Line, peak metamorphic conditions reached sillimanite K-feldspar (fig. 16). Hames and others (1991) dated hornblende from the Taconian staurolite zone two quadrangles to the north by $^{40}Ar/^{39}Ar$ and obtained an age of approximately 445 Ma that they interpret as growth ages at the peak of Taconian metamorphism. This age closely agrees with ages from the syn-tectonic Candlewood Granite (443 ± 7 Ma) and the granite leucosomes in the migmatite gneiss (444 ± 6 Ma) (Walsh and others, in press) suggesting that peak metamorphism, melting, and intrusion were contemporaneous during D2. Subsequent Acadian metamorphism produced fibrolite-muscovite assemblages during the Devonian (Hames and others, 1991). East of Cameron's Line, mineral assemblages reflect staurolite-kyanite grade Acadian metamorphism, which Hames and others (1991) dated just to the north at 390 to 400 Ma. Sillimanite east of Cameron's Line occurs within xenoliths and along the contact with the Brookfield Gneiss, either reflecting a relict Taconian assemblage or a relict contact metamorphic assemblage from the intrusion of the Brookfield. Coarse-grained granoblastic textures in the sillimanite bearing rocks around the Brookfield Gneiss suggest that the mineral is a product of contact metamorphism.

Hames and others (1991) suggest that Acadian metamorphism in the area was associated with the development of a penetrative fabric. The distinction between a Taconian D2 fabric and a younger Acadian fabric that pre-dates the late stage cleavage (S3) was not made in this map. The cover rocks on both sides of Cameron's Line have a maximum of two generations of foliations with associated isoclinal folds, and no evidence of a third generation of penetrative folds was seen in the area. Geochronologic data show Ordovician ages from syn D2, syn-tectonic intrusions in the area ranging from 453 to 443 Ma (Walsh and others, in press; Sevigny and Hanson, 1985). The dominant penetrative foliation in the area is interpreted as S2 on both sides of Cameron's Line. These data do not support two distinct sets of penetrative foliation, one Taconian and one Acadian. It is possible, however, that reactivation of the dominant foliation occurred during the Acadian and perhaps this explains the mylonitization along the Fort Mountain fault and the progressive reorientation of mineral lineations from west to east across Cameron's Line (fig. 11). Further evidence for the lack of a significant Acadian deformation event in the area comes from the relict granoblastic textures in the sillimanite-bearing rocks around the Brookfield gneiss. If the sillimanite reflects relict contact metamorphism at or about the time of intrusion (c. 451 Ma), then it implies that subsequent Acadian deformation in the area was weak because the rocks are dominated by the granoblastic texture of intergrown sillimanite, not a later lepidoblastic fabric.

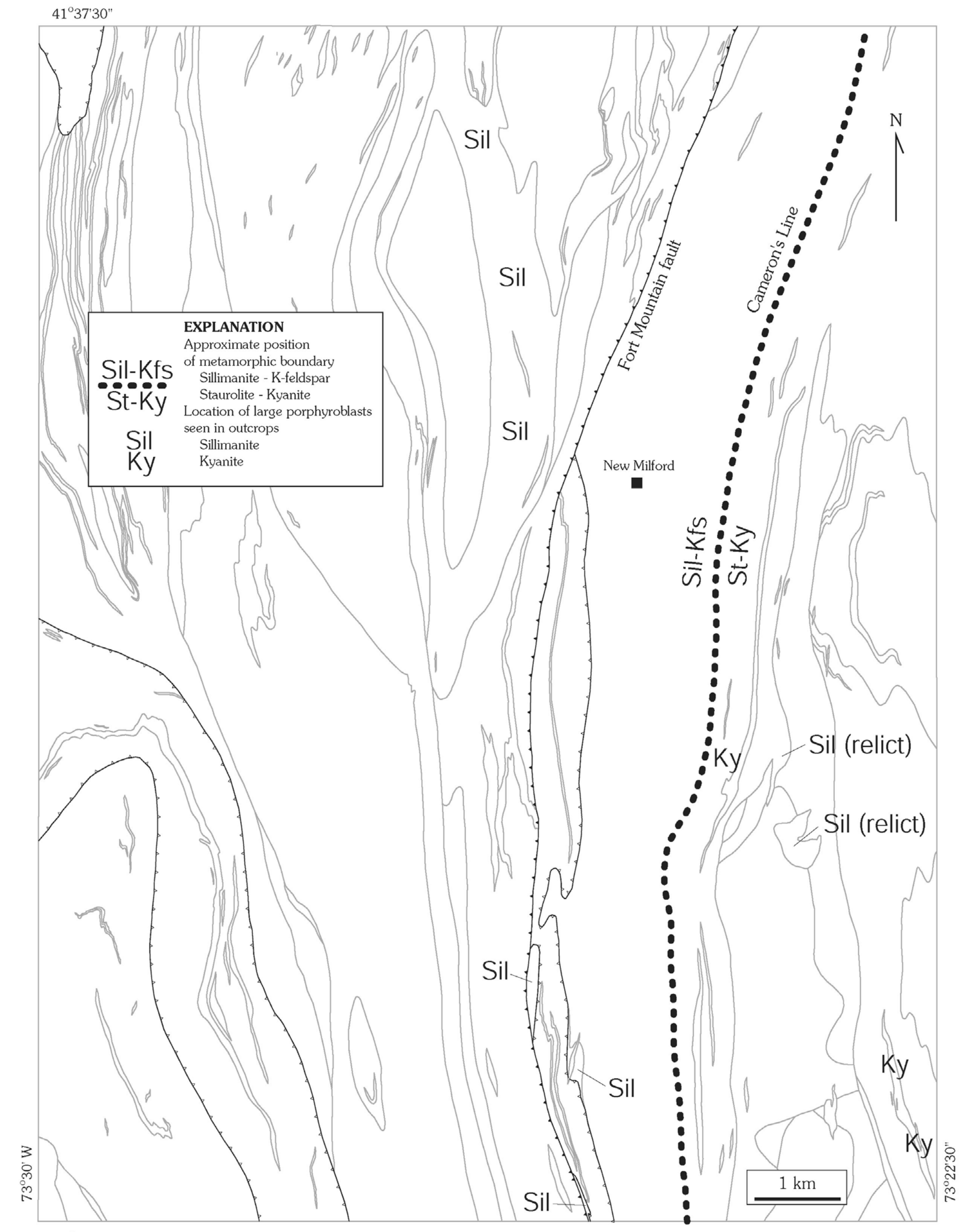


Figure 16. Simplified map of the New Milford quadrangle showing peak metamorphic grade during the Paleozoic. Rocks west of Cameron's Line reached sillimanite-K feldspar metamorphic grade in the Ordovician and were later overprinted by fibrolite-muscovite grade metamorphism in the Devonian. Cameron's Line is only an approximate location for the boundary between the different metamorphic conditions because the rocks in the Stockbridge Formation immediately west of the fault are not aluminous assemblages. Locations of large sillimanite-fibrolite-quartz-muscovite knots seen in outcrops of the Dalton Formation are indicated by "Sil". Rocks east of Cameron's Line reached staurolite-kyanite conditions in the Devonian. Locations of large kyanite porphyroblasts in the Ratlum Mountain Schist are indicated by "Ky". Locations of large sillimanite porphyroblasts in the Ratlum Mountain Schist near the Brookfield Gneiss are indicated by "Sil" and are interpreted as evidence of relict Ordovician contact metamorphism. Geologic contacts from Plate 1 are shown in gray.

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DESCRIPTION OF MAP UNITS

(Major minerals listed in order of increasing abundance)

ORDOVICIAN INTRUSIVE ROCKS

Oqv - **Quartz veins (Ordovician?)** – Quartz veins and garnet-biotite-quartz veins shown as map units or as symbols. Two mapped garnet-biotite-quartz veins crop out on the west side of Rocky Hill in the southeastern corner of the map. Outcrop-scale quartz veins generally measure 1- to 2-m-thick and are shown by strike and dip symbols; smaller quartz veins are ubiquitous and have not been mapped separately.

Op – **Pegmatite (Ordovician?)** – White to light gray, granitic pegmatite occurs as map-scale intrusive bodies and outcrop-scale dikes. Pegmatite contains accessory muscovite, biotite, and tourmaline. Tabular outcrop-scale dikes generally measure 1- to 2-m-thick and are shown by strike and dip symbols; smaller, more irregular pegmatite masses are ubiquitous and have not been mapped separately.

Og & Ocg – **Granite (Ordovician)** – Medium- to light-gray, tan- or white-weathering, moderately to well-foliated, fine- to medium-grained, muscovite-biotite-quartz-plagioclase-microcline granite. Locally contains accessory garnet and tourmaline. The large mass underlying Candlewood Mountain, Pine Knob, and Boardman Mountain is herein referred to as the Candlewood Granite and is shown on the map as Ocg; it is locally porphyritic with phenocrysts (up to 1 cm) of microcline. Many smaller intrusive bodies of granite (Og) occur throughout the map area; larger bodies are shown as individual map units and smaller outcrop-scale dikes are shown with strike and dip symbols. The U/Pb zircon SHRIMP age of the Candlewood Granite is 443 ± 7 Ma (Walsh and others, in press). A granite dike that cuts the Brookfield Gneiss south of Town Hill yields a U/Pb zircon SHRIMP age of 453 ± 10 Ma (Walsh and others, in press).

Brookfield Gneiss (Ordovician) – Dark-gray to black and white, medium- to coarse-grained, non-foliated to well-foliated, quartz-biotite-hornblende-plagioclase dioritic gneiss. The large intrusive mass in the eastern part of the map area is the northern end of the Brookfield Gneiss at its type locality (Rodgers, 1982, 1985). Five smaller diorite dikes occur along the margins of the main intrusive body; the dikes are labeled “Obd” on the map. Subdivisions within the Brookfield Gneiss are based on a detailed petrologic and geochemical study by Sperandio (1974, p. 51); the different sub-units include: Obd – diorite, Obqd – quartz diorite, Obgq – granodiorite, Obqm – quartz monzonite, and Obg – granite. An age of 451 ± 1 Ma was obtained from a biotite quartz diorite phase of the Brookfield Gneiss in the Danbury quadrangle (Sevigny and Hanson, 1995).

AUTOCHTHONOUS PALEOZOIC METASEDIMENTARY ROCKS WEST OF CAMERONS LINE

Walloomsac Formation (Ordovician)
Ow – Biotite schist – Dark gray to black, rusty weathering, coarse-grained, chlorite-muscovite-sillimanite-k feldspar-biotite-quartz-plagioclase schist. Sillimanite is fibrolitic and locally occurs as porphyroblastic knots replaced by quartz and muscovite. Locally contains garnet porphyroblasts, interlayered muscovite-biotite-quartz-plagioclase granofels, and discontinuous pods and lenses of calc-silicate rock generally consisting of quartz, plagioclase, epidote, diopside, and hornblende. Schist contains mappable layers of calcite marble (Owm). Bedding is poorly preserved.

Owm – Calcite marble – Light gray to light yellowish white, rusty orange to tan weathering, moderately foliated to massive, quartz-tremolite-diopside-phlogopite-calcite marble. The marble occurs as mappable layers that range in thickness from several meters to tens of meters. Where the marble horizons are only several meters thick, their thickness is exaggerated on the map. Bedding is poorly preserved.

Stockbridge Formation (Ordovician and Cambrian)
OCs - Dolomite marble – Light-gray and white, chalky white weathering, massive to thickly bedded, weakly to moderately foliated, tremolite-dolomite marble. Locally contains thin lenses of coarse-grained sphene-quartz-phlogopite-diopside-tremolite calc-silicate rock, thin beds of light-gray and white calcite marble and rare, rusty weathering calcareous schist.

OCsq – Feldspathic quartzite – Light- to medium-gray, tan-weathering, well foliated, muscovite-k feldspar-biotite-plagioclase-quartz granofels to quartzite with mm-scale quartz-feldspar laminations that impart a pinstripe texture. Contains chlorite-muscovite-biotite-quartz-plagioclase veins and knots. Only exposed in the northeastern part of the quadrangle at one roadcut on the west side of U.S. Route 202, within the main belt of Stockbridge Formation. Contacts with the surrounding dolomite marble are not exposed.

Dalton Formation (Neoproterozoic and Cambrian)
CZd – Sillimanite-biotite schist – Gray to dark gray, rusty weathering, coarse-grained, ±chlorite-muscovite-sillimanite-k feldspar-biotite-quartz-plagioclase schist and tan muscovite-biotite-plagioclase-quartz granofels to pinstripe gneiss. Sillimanite is fibrolitic and locally occurs as porphyroblastic knots (up to 2 cm) that show replacement by quartz and muscovite. Locally contains garnet porphyroblasts. Interlayered granofels represent relict bedding and occur as layers up to 30 cm thick. Granofels layers are more abundant near the base. In the quarry north of Boardman Bridge, the sharp contact with the overlying Stockbridge Formation is exposed and the Dalton at the contact contains thin (<5 cm) discontinuous lenses of calc-silicate rock. Schist contains mappable layers of quartzite and small-pebble conglomerate (CZdq).

CZdq - Quartzite and small-pebble conglomerate – Gray to light gray, tan weathering, poorly foliated to laminated, gritty muscovite-biotite-plagioclase-quartz granofels, feldspathic quartzite, and gritty to vitreous quartzite. Locally contains sub-angular pebbles, largely of quartz, up to 1 cm and pebbly grit or conglomerate horizons up to 35 cm thick. Occurs at the contact with the basement rocks or throughout the lower part of the schist unit (CZd). Contacts with the schist unit are both sharp and gradational by intercalation.

ALLOCHTHONOUS PALEOZOIC METASEDIMENTARY ROCKS WEST OF CAMERONS LINE

Manhattan Schist (Neoproterozoic and Cambrian)
CZm - Biotite schist – Gray to dark-gray, rusty weathering, very coarse grained ±sillimanite±garnet-muscovite-biotite-quartz-plagioclase schist with abundant quartz and k-feldspar leucosomes, pegmatite, and quartz veins. Leucosomes and vein material generally measure several cm thick and are generally parallel to the early (S1) foliation. Bedding is poorly preserved.

CZma – Amphibolite – Dark-green to black, medium- to coarse-grained, well foliated, ±biotite-quartz-plagioclase-hornblende amphibolite. Locally contains pale-green epidote-rich laminae and light-purple garnet-rich horizons. Occurs as layers within the schist unit (CZm) ranging from several meters to tens of meters thick. Contacts with the schist are sharp.

ALLOCHTHONOUS PALEOZOIC METASEDIMENTARY ROCKS EAST OF CAMERONS LINE

Ratlum Mountain Schist (Ordovician and Cambrian)
OCr - Schist – Silvery gray to medium- or dark-gray, tan to light gray weathering, medium grained, ±staurolite±kyanite-garnet-muscovite-biotite-plagioclase-quartz schist. Locally contains thin (up to 30 cm) interlayered muscovite-biotite-plagioclase-quartz granofels. Locally contains chlorite, magnetite, and ilmenite. Locally, schist near the contact with the Brookfield Gneiss and schist xenoliths within the gneiss, especially at Wolf Pit Mountain, contain abundant idioblastic garnet and prismatic sillimanite due to contact metamorphism.

OCra - Amphibolite – Dark-green to black, medium-grained, well foliated, quartz-biotite-plagioclase-hornblende amphibolite. Occurs as layers within the schist unit (OCr) ranging from several meters to a couple hundred meters thick. Contacts with the schist are sharp.

OCrk - Coarse kyanite schist – Silvery gray to medium-gray, light-gray weathering, medium- to coarse-grained, ±staurolite-kyanite-garnet-muscovite-biotite-plagioclase-quartz schist with coarse kyanite porphyroblasts up to 8 cm long. Kyanite porphyroblasts are partially replaced by sericite and quartz. Occurs as an approximately 100-200 m-wide zone in the southeastern corner of the map. The contact with the OCr unit is gradational.

Rowe Schist (Ordovician and Cambrian)
OCrfq - Feldspathic granofels and biotite schist -- Light gray, tan weathering, sandy textured, garnet-muscovite-biotite-plagioclase-quartz granofels layers up to 50 cm thick interlayered with gray, tan to light gray weathering, medium grained, ±staurolite±garnet-muscovite-biotite-plagioclase-quartz schist. Granofels layers make up greater than 50 percent of the unit. Locally

contains garnet porphyroblasts and chlorite after garnet. Schist resembles OCrg unit. The contact with the garnetiferous schist (OCrg) is gradational by intercalation.

OCrg - Garnetiferous schist – Medium gray to dark gray, rusty weathering, medium- to coarse-grained, ±staurolite±kyanite-garnet-muscovite-biotite-plagioclase-quartz schist with coarse garnet porphyroblasts up to 1 cm. Garnet porphyroblasts are generally unaltered, but are locally replaced by chlorite. Locally contains thin (up to 30 cm) interlayered rusty weathering muscovite-biotite-plagioclase-quartz granofels. Locally contains chlorite after garnet. The contact with the Ratlum Mountain Schist (OCr) is gradational by intercalation.

MESOPROTEROZOIC BASEMENT ROCKS

OYmig - Migmatite gneiss (a rock of mixed parentage and age; older components are older than 1311 Ma and younger components are Late Mesoproterozoic and Ordovician) – Stromatic migmatite containing very well-layered, gray biotite-microcline-quartz-plagioclase gneiss, biotite-quartz-plagioclase gneiss, and amphibolite with abundant layer-parallel white to pink leucosomes of granitic pegmatite and granitic gneiss. The host rock for the migmatite gneiss (OYmig) is the layered biotite gneiss unit (Ybg). The contact between OYmig and Ybg is gradational over a distance of tens of meters and is defined based on the greater abundance of leucosomes within OYmig. Locally, the migmatite is dominated by leucosomes to the extent that the original character of the Ybg host rock is almost completely replaced. In addition to abundant layer-parallel leucosomes, the migmatite gneiss contains abundant dikes and veins of light-gray to pink granitic gneiss, aplite, and pink migmatitic granite gneiss that post-date the Mesoproterozoic folding and gneissosity. These younger intrusions are deformed and contain the dominant fabric (F2 folds and S2 foliation) found in the cover sequence rocks and Ordovician granites, suggesting that the migmatite gneiss has a composite history of Precambrian migmatization by anatexis followed by Ordovician migmatization by injection. U-Pb zircon SHRIMP ages of 1057 ± 10 Ma (sample NM576B) and 444 ± 6 Ma (sample NM576A) from samples collected northwest of Green Pond indicate Mesoproterozoic and Ordovician ages for the different generations of migmatite (Walsh and others, in press). A single map unit labeled Ymig is shown in the southwestern corner of the map. There the unit consists of stromatic migmatite gneiss and well-foliated granitic gneiss without the abundant younger (Ordovician) injection migmatite and dikes seen in the central part of the map. This area of migmatization may be locally related to the intrusion of the Danbury augen granite.

Yag – Danbury augen granite of Clarke (1958) – Coarse-grained, weakly to moderately well-foliated hornblende-biotite-plagioclase-microcline granite gneiss with deformed phenocrysts of microcline up to 4 cm across and 10 cm long. Clarke (1958) named the Danbury augen granite for exposures on the west side of Lake Candlewood in the towns of Danbury and New Fairfield, Connecticut. Yag does not possess the older (YS1) gneissosity seen locally in the other basement gneisses, but xenoliths do contain the older fabric, suggesting that the augen granite entirely post-dates the earlier deformation event. Yag is variably deformed by the Mesoproterozoic foliation (YS2). Contacts with the adjacent rock units are not exposed, but the augen granite contains xenoliths of amphibolite, hornblende gneiss, layered biotite gneiss, and pink granite gneiss. Yag occurs in three separate belts in the map area. The largest body is a pluton exposed in the southwestern part of the map, west of Lake Candlewood, that is coextensive with Clarke's (1958) type locality to the south. Two smaller bodies intrude the gneisses of the New Milford massif along its eastern margin, and one of these, at Mt. Tom, extends into the adjacent Kent quadrangle to the north (Jackson, 1980). Unlike the larger pluton in the southwestern part of the quadrangle, the two smaller plutons to the northeast are highly deformed and mylonitized along a fault zone that parallels the dominant S2 foliation. This fault zone forms the eastern border of the New Milford massif. U-Pb zircon SHRIMP age of 1045 ± 8 Ma (sample NM100, Walsh and others, in press) is from Yag on the west side of Pond Mountain in the southwestern corner of the map.

Ybgg – Biotite granitic gneiss – Well-foliated, moderately layered, gray biotite-microcline-quartz-plagioclase granitic gneiss with a generally uniform texture and composition. Occurs northwest of downtown New Milford as a single mapped body in the New Milford massif. Contacts with the adjacent Ybg unit are not exposed, but Ybgg is interpreted as an intrusive body into Ybg, as it resembles the thin layers of leucocratic biotite granitic gneiss found within the Ybg, and does not possess the compositional heterogeneity associated with Ybg. U-Pb zircon SHRIMP age of 1050 ± 14 Ma (Sample NM628, Walsh and others, in press) is from the biotite granitic gneiss unit. Chemically, the sampled gneiss is quartz monzonite.

Ygg – Pink granite gneiss – Well-foliated, tan weathering, light-pink biotite-quartz-plagioclase-microcline granite gneiss with a generally uniform texture and composition. Contacts with the adjacent rock units are not exposed, but Ygg contains xenoliths of layered biotite gneiss and amphibolite and is interpreted as an intrusive body. A sample collected on the East Aspetuck River yields a U-Pb zircon SHRIMP age of 1311 ± 7 Ma (Sample NM174, Walsh and others, in press).

Yhg - Hornblende-plagioclase gneiss and amphibolite – Poorly to well-foliated, fine to medium grained epidote-biotite-quartz-hornblende-plagioclase gneiss to coarse-grained hornblende-plagioclase gneiss. Layers of amphibolite and hornblende gneiss, too small to map separately, occur throughout the layered biotite gneiss (Ybg) and migmatite gneiss (OYmig). Xenoliths of the mafic rocks also occur within the pink granite gneiss (Ygg) and Danbury augen granite (Yag). The belt of Yhg in the southwestern corner of the map is generally coarse-grained and weakly foliated, and may be, in part, intrusive.

Ycs - Calc-silicate rock – Purplish gray, well-foliated, actinolite-diopside-biotite-plagioclase-quartz gneiss and poorly foliated granofels, and pale green, massive, quartz-sphene-calcite-biotite-tremolite-plagioclase-diopside granofels. Diopside is altered to uralite. The rock contains accessory tourmaline, apatite, and serpentine minerals, the latter of which occurs on joint or fault surfaces. The calc-silicate rock is exposed in an abandoned quarry on the east side of Candlewood Mountain. There it is in sharp contact with the layered biotite gneiss to the west and the biotite-sillimanite schist of the Dalton Formation (CZd) to the east.

Ybg – Layered biotite gneiss – Well-layered light-gray biotite-microcline-quartz-plagioclase granite gneiss, biotite-quartz-plagioclase gneiss, amphibolite, quartz-rich biotite gneiss, and rare vitreous quartzite and calc-silicate gneiss. Interpreted as a paragneiss with abundant layer-parallel sills of granitic gneiss. Light-gray leucocratic biotite-microcline-quartz-plagioclase granitic gneiss occurs everywhere within the Ybg unit as layers ranging from centimeters to meters thick. Original protolith of Ybg may have consisted of mafic and felsic volcanic rocks interspersed with paragneiss. Layering of the leucocratic gneiss is generally sub-parallel to the dominant foliation in the rock, but locally lenses of the leucocratic gneiss converge and appear to cross-cut interlayered amphibolite and paragneiss. U-Pb zircon SHRIMP age of 1048 ± 11 Ma (Sample NM772, Walsh and others, in press) collected on Long Mountain is from a 30 cm thick layer of leucocratic biotite granite gneiss that is bounded by 20 cm and 10 cm thick layers of amphibolite.

APPENDIX

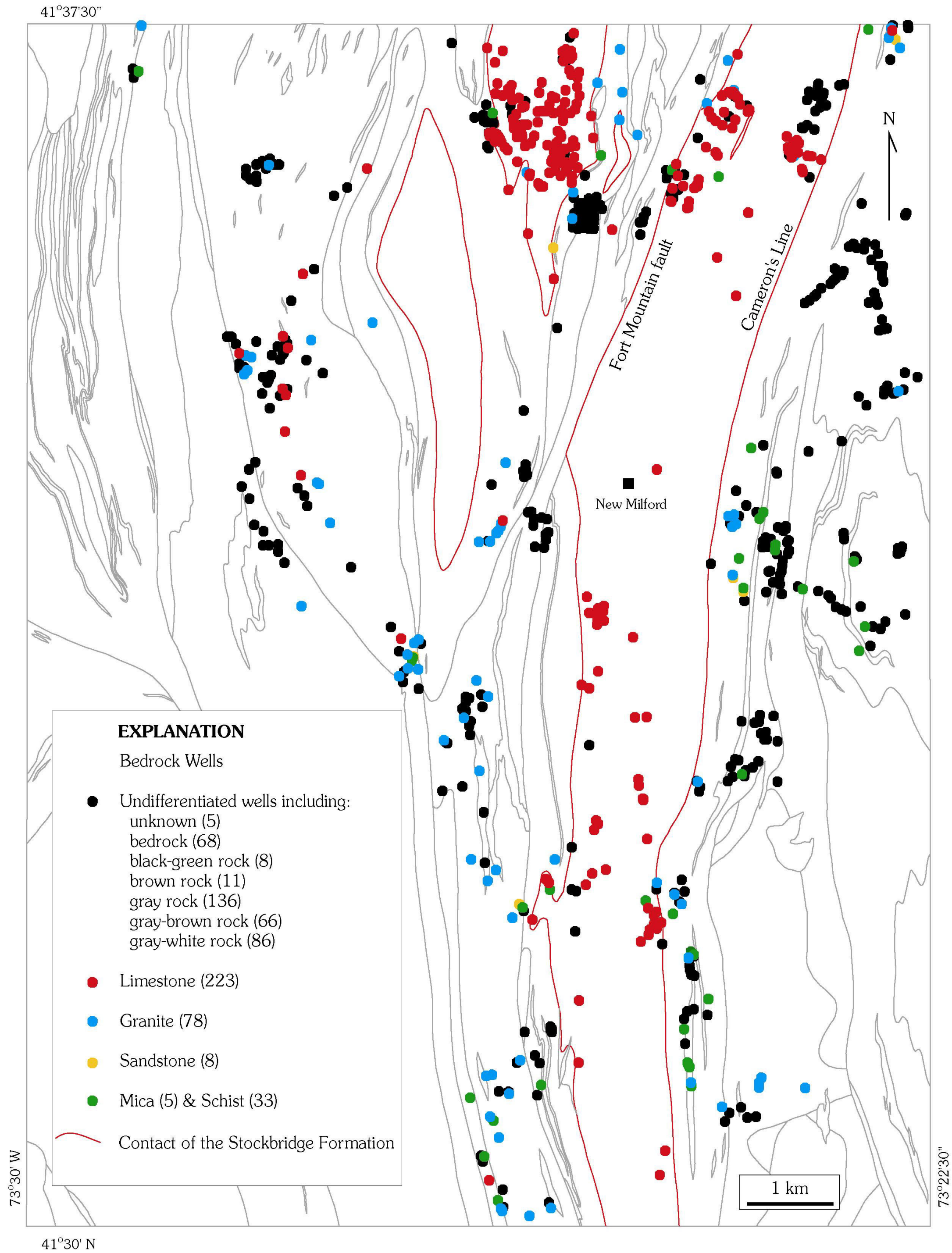

Figure 17. Simplified map of the New Milford quadrangle showing 721 bedrock wells and the principal rock type encountered according to driller's well completion reports. Rock types listed are from an unpublished compilation by the Water Resources office of the USGS in Hartford, Connecticut. Due to the limited reliability of driller's reports, only wells with reported "limestone" were used to help constrain the extent of the Stockbridge Formation where it is not exposed. No other units were mapped with these data.