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An Investigation of the Stratigraphy and Tectonics of the Kent Area, Western Connecticut

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AN INVESTIGATION OF THE STRATIGRAPHY AND TECTONICS OF THE KENT AREA, WESTERN CONNECTICUT

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INTRODUCTION

The detailed stratigraphy and tectonics of the complexly deformed autochthon and allochthon of the Manhattan Prong is correlated with a similar stratigraphy and structural framework of the Taconic area of western Connecticut. This correlation (Robinson and Hall, 1980; Hall, 1980) is based on detailed mapping in both the Manhattan Prong (Hall, 1968, 1976, and 1980) and the southern Taconics (Ratcliffe, 1969, 1975; Zen, 1969, 1972). Since the Kent area (Fig. 1) lies between these two regions, correlative stratigraphy (Fig. 2) and tectonic history can be demonstrated. This trip will examine the detailed stratigraphy of the autochthon and allochthon of the Kent area, and the geometry and relative timing of deformation.

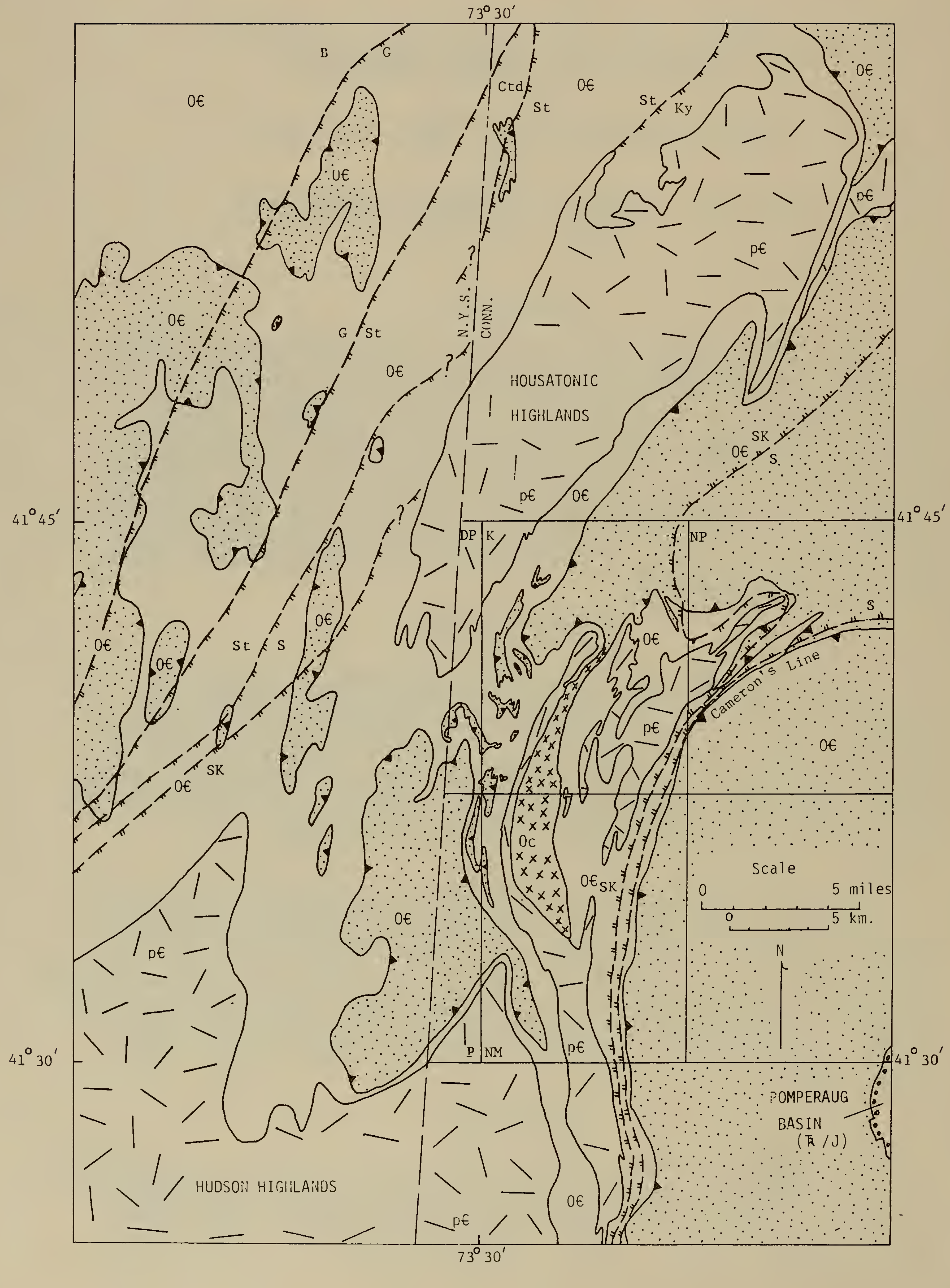
REGIONAL SETTING

Precambrian rocks are exposed in the Housatonic Highlands (Stop 1), the Hudson Highlands, and in several locations within the Kent area (Stop 6). Except for the occurrence of Triassic/Jurassic rocks in the Pomperaug Basin, the rocks in western Connecticut and adjacent parts of New York State are metamorphosed Lower Paleozoic miogeoclinal and eugeoclinal rocks (Fig. 1). Paleozoic plutons, such as the Ordovician Candlewood Lake Pluton (Mose and Nagel, appended to this report; Stop 4) in the Kent area (Fig. 1), are also present in the region.

Rocks in the western and northern portions of the Kent area are in the sillimanite-K-feldspar zone. The grade of Paleozoic regional metamorphism decreases both eastward and westward from this high grade zone (Balk, 1936; Barth, 1936; Vidale, 1974; Jackson, 1980) (Fig. 1). The metamorphic history of the rocks is complex, as Acadian metamorphic effects overlap Taconian metamorphic effects in the region. With the high metamorphic grade there is an intimate structural involvement of the Precambrian basement with the Paleozoic cover rocks (Hall, *et al*., 1975; Hall, 1980).

STRATIGRAPHY

Precambrian rocks of igneous and sedimentary origin are unconformably overlain by Cambrian quartzites and schists of the Lowerre Quartzite (Stops 1, 5 and 6) and the Cambrian/Ordovician carbonate bank Inwood Marble sequence (Figs. 2 and 4). The eastern exposures of the Lowerre



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EXPLANATION

ROCK TYPES

Triassic and/or Jurassic

Ꞧ/J — Sedimentary and igneous rocks

unconformity

Cambrian and/or Ordovician

Oc — Granitic rocks of the Candlewood Lake Pluton

O€ — Miogeoclinal autochthonous metamorphosed sedimentary rocks

O€ — Eugeoclinal allochthonous metamorphosed sedimentary and igneous rocks

unconformity

Precambrian

p€ — Metamorphosed sedimentary and igneous rocks

SYMBOLS

Thrust fault
(teeth in allochthon)

Isograds
(teeth in high grade rocks)

SK	Sillimanite/K-feldspar
S	Sillimanite
Ky	Kyanite
St	Staurolite
Ctd	Chloritoid
G	Garnet
B	Biotite

Quadrangles

K	Kent
DP	Dover Plains
P	Pawling
NM	New Milford
NP	New Preston

Figure 1. Generalized geologic map of western Connecticut and adjacent eastern New York State (compiled from Balk, 1936; Barth, 1936; Fisher, et.al., 1972; Vidale, 1974; Robinson and Hall, 1980; Zen, 1981). The Kent area includes the Kent (Jackson, 1980), New Preston (Gates, 1952; Dana, 1977), New Milford (Caldwell, personal communication, 1975), and the Connecticut portions of the Dover Plains and Pawling (Jackson, reconnaissance mapping) quadrangles.

AGE \ LOCATION	KENT QUADRANGLE THIS REPORT	MANHATTAN PRONG AREA, NEW YORK Hall, (1968a, 1968b, 1976)	DUTCHESS COUNTY NEW YORK Fisher, (1962a,1962b) Knopf, (1962)	WESTERN MASSACHUSETTS AND CONNECTICUT Zen and Hartshorn, (1966) Zen, (1967)	WESTERN VERMONT Doll, et.al., (1961) Zen, (1961)
MIDDLE ORDOVICIAN	MANHATTAN A: GRANULITE MEMBER CALCITE MARBLE MEMBER	MANHATTAN SCHIST: A-MEMBER INTERBEDDED MARBLE AND SCHIST	WALLOOMSAC FORMATION BALMVILLE LIMESTONE	WALLOOMSAC FORMATION INTERBEDDED LIMESTONE AND SCHIST	IRA FORMATION WIPPLE MARBLE MEMBER
EARLY ORDOVICIAN	ERODED	ERODED	STOCKBRIDGE-WAPPINGER GROUP: COPAKE LIMESTONE ROCHDALE LIMESTONE HALCYON LAKE	STOCKBRIDGE FORMATION: UNIT-G UNIT-F UNIT-E UNIT-D	CHIPMAN FORMATION BASCOM FORMATION CUTTING DOLOMITE SHELBURNE FORMATION
CAMBRIAN	INWOOD MARBLE: B-MEMBER A-MEMBER	INWOOD MARBLE: C-MEMBER B-MEMBER A-MEMBER	STOCKBRIDGE-WAPPINGER GROUP: BRIARCLIFF DOLOMITE PINE PLAINS FM. STISSING DOLOMITE	STOCKBRIDGE FORMATION: UNIT-C UNIT-B UNIT-A	CLARENDON SPRINGS DANBY FORMATION WINOOSKI DOLOMITE MONKTON QUARTZITE DUNHAM DOLOMITE
CAMBRIAN	LOWERRE QUARTZITE	LOWERRE QUARTZITE	POUGHQUAG QUARTZITE	CHESHIRE QUARTZITE DALTON FORMATION	CHESHIRE QUARTZITE DALTON FORMATION
PRECAMBRIAN	GNEISSES	FORDHAM GNEISS	GNEISSES	BERKSHIRE MASSIF GNEISSES	MOUNT HOLLEY COMPLEX

Figure 2. Proposed regional correlation of the miogeosynclinal stratigraphic subdivisions in the Kent quadrangle, based on a similar diagram of Hall (1968a, 1968b, 1976).

Quartzite consist of schistose granulite and schist (Stops 5 and 6), whereas quartzite and conglomeratic quartzite are common in the west (Stop 1). This may represent a time-transgressive sequence with the rocks in the east deposited in deeper water and prior to those in the west. The base of the Inwood Marble consists of a thick-bedded dolomite marble with thin interbedded quartz granulite, calc-silicate, calcite marble, and dolomite marble higher in the section (Stop 2 and Optional Stop A). These rocks in turn are unconformably overlain by Middle Ordovician calcite marble and schistose granulite of Manhattan A (Stops 2 and 4). Locally, Manhattan A rocks are in direct contact with Inwood Marble (Stop 2) or locally, with Lowerre Quartzite (Fig. 3).

The autochthonous stratigraphy is physically overlain by an allochthonous sequence of Cambrian and/or Ordovician eugeoclinal schists, granulites, gneisses and amphibolites of Manhattan C and the Moretown Formation (Fig. 3). The detailed stratigraphy within Manhattan C is seen at Optional Stop B. The correlation between the autochthonous and allochthonous rocks of the Kent area is shown in Figure 4. A major tectonic and stratigraphic boundary, Cameron's Line (Rodgers, et al., 1956; Merguerian, in press), occurs east and southeast of the rocks of the Kent area (Fig. 1). Mafic and ultramafic igneous bodies occur locally along its trend. A sequence of schist, quartzite, amphibolite, and gneiss of the eugeoclinal Moretown Formation is east of Cameron's Line (Fig. 3).

STRUCTURAL GEOLOGY

Basement in the Housatonic Highlands and elsewhere within the Kent area underwent a Precambrian, presumably Grenvillian, deformation with the development of folds and associated axial plane foliation. Previously these folded rocks were in turn intruded by Late Precambrian granite that presumably became gneissic during Paleozoic deformation (Stops 1 and 6). Precambrian structural elements are truncated by the unconformity beneath the overlying Cambrian Lowerre Quartzite (Stops 1 and 6).

The geologic map pattern (Fig. 3) is the result of a sequence of thrust faults and several major stages of folding during the Paleozoic (Jackson, 1980). Taconic orogenic activity produced thrust faults and major isoclinal folds (Figs. 5 and 6) with a well developed axial plane schistosity which is the dominant schistosity of the Paleozoic rocks in the area. The thrust sheets formed prior to or contemporaneous with this folding. Separate thrust sheets transported Cambrian Manhattan C rocks westward over the autochthonous stratigraphy (Stops 3 and 4 and Optional Stop B). It is proposed that Manhattan C was deposited at nearly the same time as, or somewhat earlier than, the Lowerre Quartzite, but further offshore to the east. The rocks reached the sillimanite-K-feldspar grade of metamorphism during Taconian deformation and the Candlewood Lake Pluton (Stop 4) and related pegmatites invaded the autochthonous and allochthonous rocks while these rocks were still hot (Jackson, 1980). The radiometric dating of this pluton (Mose and Nagel, P1-6

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STOP 3
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€1
STOP 4
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€1
B'
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B
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STOP 2
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73°30" A"
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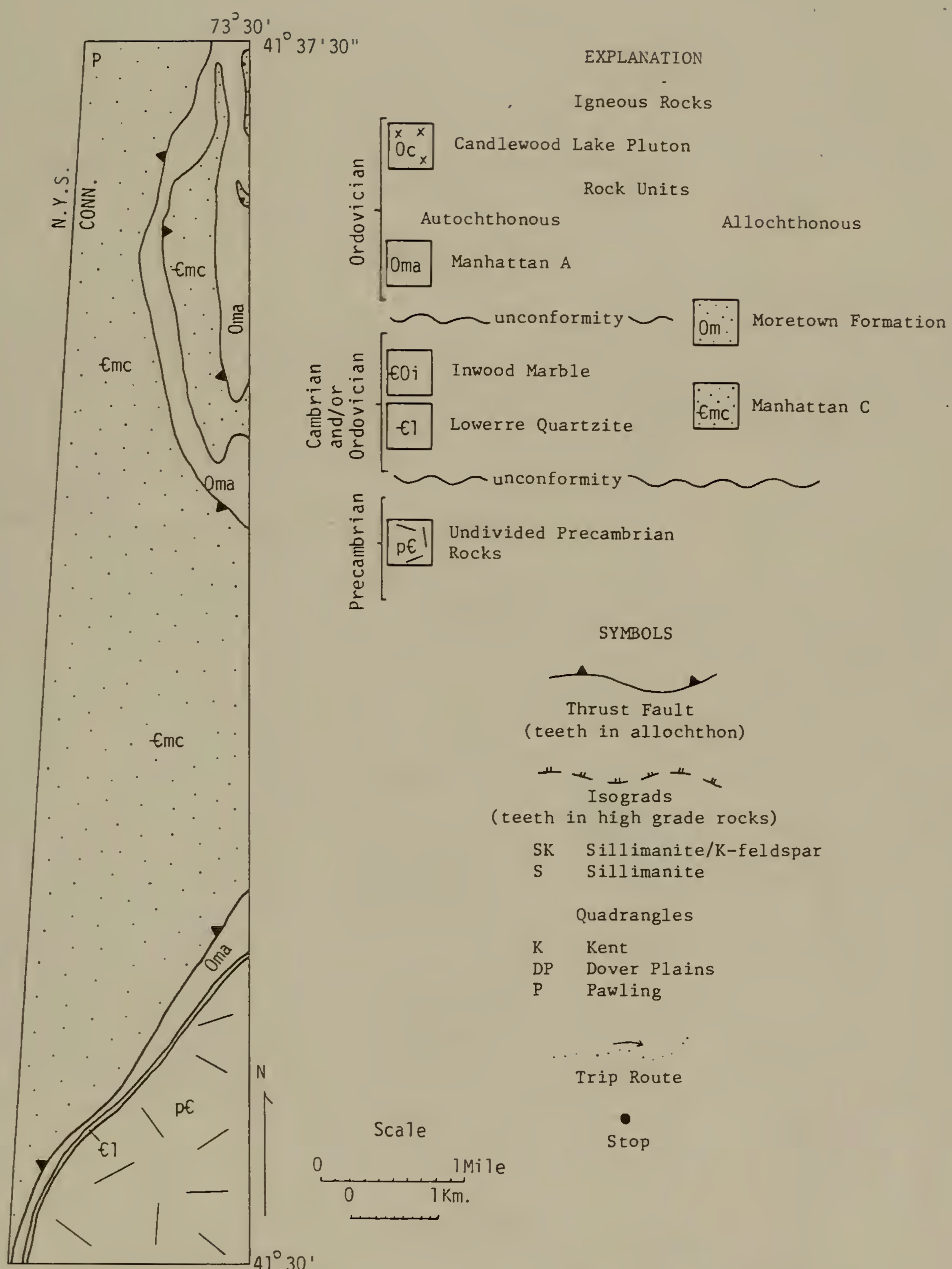


Figure 3. Generalized geologic maps of the Kent (Jackson, 1980), Dover Plains and Pawling (Jackson, unpublished reconnaissance mapping) quadrangles, indicating trip route, stops, and structural sections AA'A", BB', and CC'.

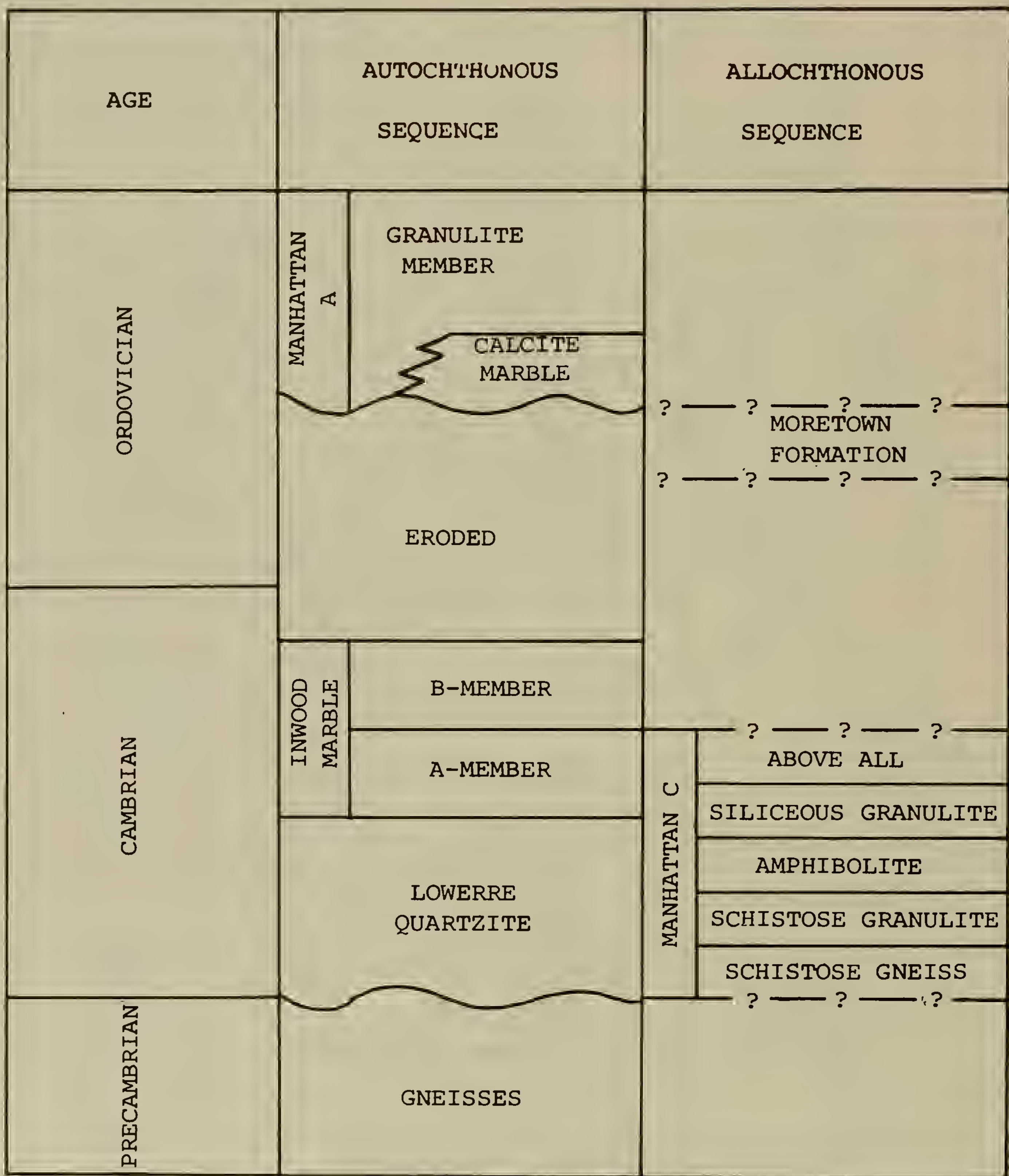


Figure 4. Proposed correlation of allochthonous rocks and autochthonous rocks in the Kent quadrangle.

appended to this report) provides a control on the timing of the various phases of deformation, so that Acadian deformation is interpreted to have followed the thrusting, early folding, and intrusion of the Candlewood Lake Pluton (Stop 4). Acadian deformation produced large-scale, nearly vertical, isoclinal to open folds, trending north or northeast. These folds dominate the map pattern (Fig. 3) and their geometry is illustrated in structure sections BB' and CC' (Fig. 6). Finally, a late stage of deformation occurred with two associated, or conjugate, sets of folds developing with respective northeast and northwest axial planar slip cleavages. A summary of the deformational history of the Kent area is provided in Figure 7.

ACKNOWLEDGEMENTS

We wish to thank the Connecticut State Geological and Natural History Survey for providing generous financial support. The cooperation extended to us by the personnel of the Kent School (Stop 1), South Kent School (Stop 3), and the Eliot D. Pratt Education Center (Stop 6) is greatly appreciated.

TRIP PURPOSE

Located between the southeastern Taconics and the Manhattan Prong, the stratigraphy and structural geology of the Kent area is critical to any regional synthesis. The purpose of this trip is to illustrate the important stratigraphic relationships and to define the deformational episodes that have effected the rocks of the area. Although they are disrupted by thrust faulting and several major episodes of folding, a clear time/stratigraphic equivalence between the autochthonous Lowerre Quartzite and the allochthonous Manhattan C is recognized. Two unconformities, one that is basal Paleozoic and another that is Middle Ordovician have been traced through the area. Radiometric dating of the Candlewood Lake Pluton, a granitic intrusive body, and the structural relationships of this pluton to the surrounding rocks indicates that major thrusting and an early, recumbent phase of folding with its associated sillimanite/K-feldspar metamorphism occurred during the Taconian orogeny. Deformation subsequent to the emplacement of the granite is inferred to be Acadian.

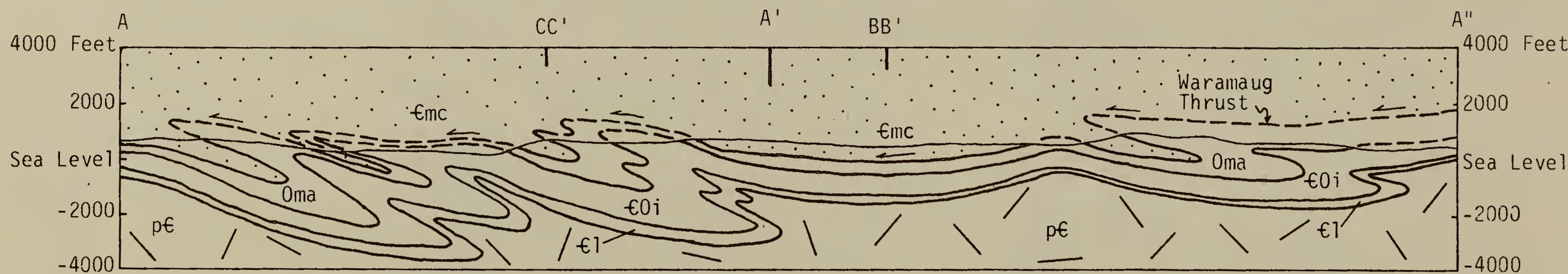


Figure 5. Generalized structure section AA'A" indicating the Waramaug Thrust and the intimate relationship between the Precambrian basement and Paleozoic cover rocks during Taconian folding, D_2. Section is drawn facing west.

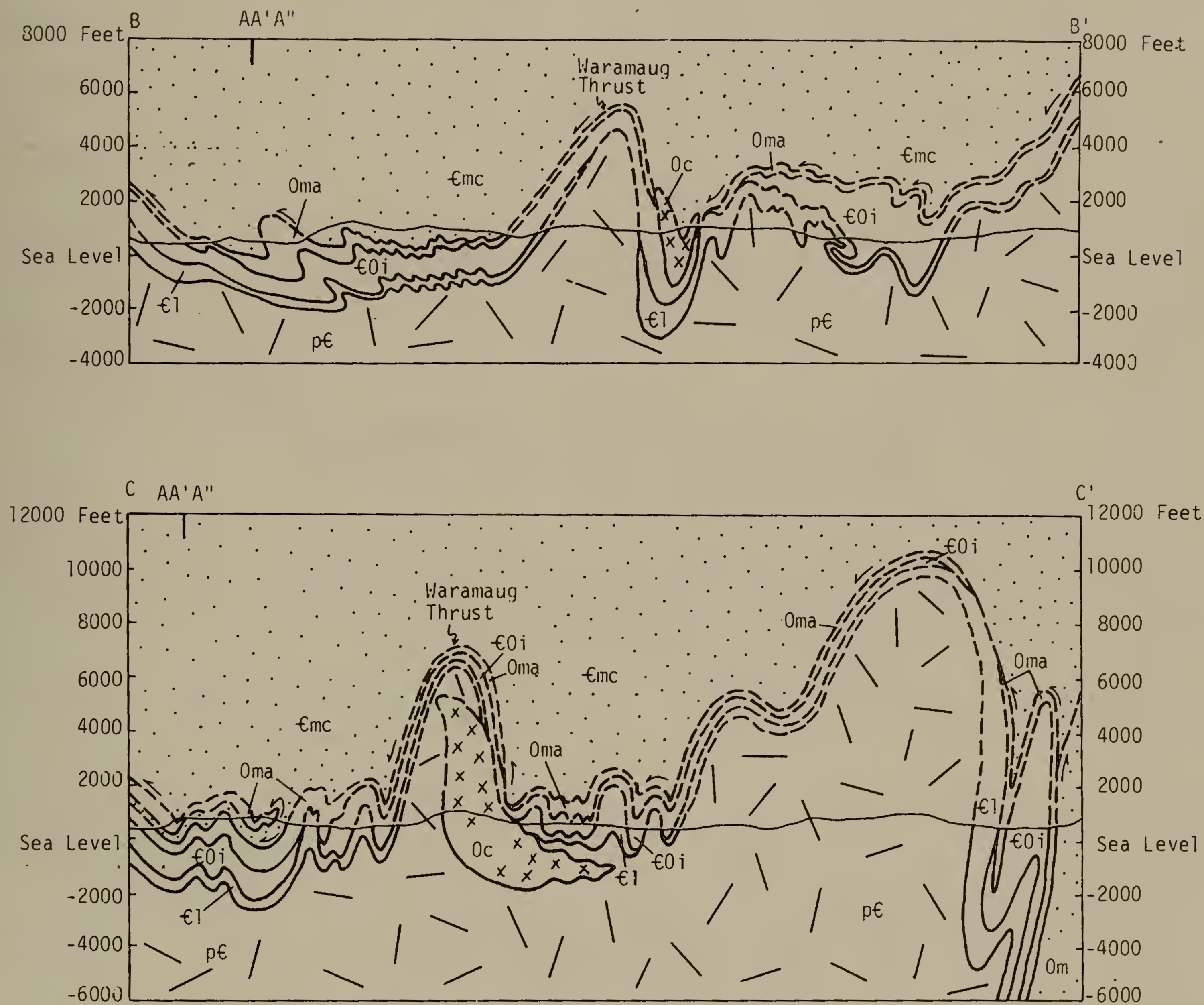


Figure 6. Generalized structural sections BB' and CC' indicating the dominance of the Acadian deformation, D_3.

DEFORMATIONAL EVENT	DESCRIPTION	IGNEOUS INTRUSION	OROGENY
D_4	Major open conjugate folds, contemporaneous northeast and northwest axial plane cleavage. Interference with D_3 folds locally producing dome and basin features.		Acadian(?)
D_3	Major isoclinal to open folds; vertical axial plane cleavage. North to northeast trending. Possible metamorphism to kyanite/staurolite grade.		Acadian
D_2	Major isoclinal folds; overturned to west; deform thrust slices; strong axial plane schistosity; peak metamorphism to sillimanite/K-feldspar grade. Thrust sheets emplaced westward, bring eugeoclinal rocks over miogeoclinal rocks. Locally, isoclinal folds developed within the sheets prior to or during sheet emplacement.	Candlewood Lake Pluton (Ordovician; Mose and Nagel, this report)	Taconian
	Middle Ordovician Unconformity Erosion associated with block faulting (?) has Manhattan A resting on Inwood Marble or locally, Lowerre Quartzite. Basal Paleozoic Unconformity		
D_1	Foliation subparallel to gneissic layering; no minor folds noted. Grade of metamorphism unknown.	Pink Granitic Gneiss truncates early foliation and gneissosity	Late Precambrian (?) Grenville

Figure 7. Chronology of tectonic events in the Kent area, Western Connecticut.

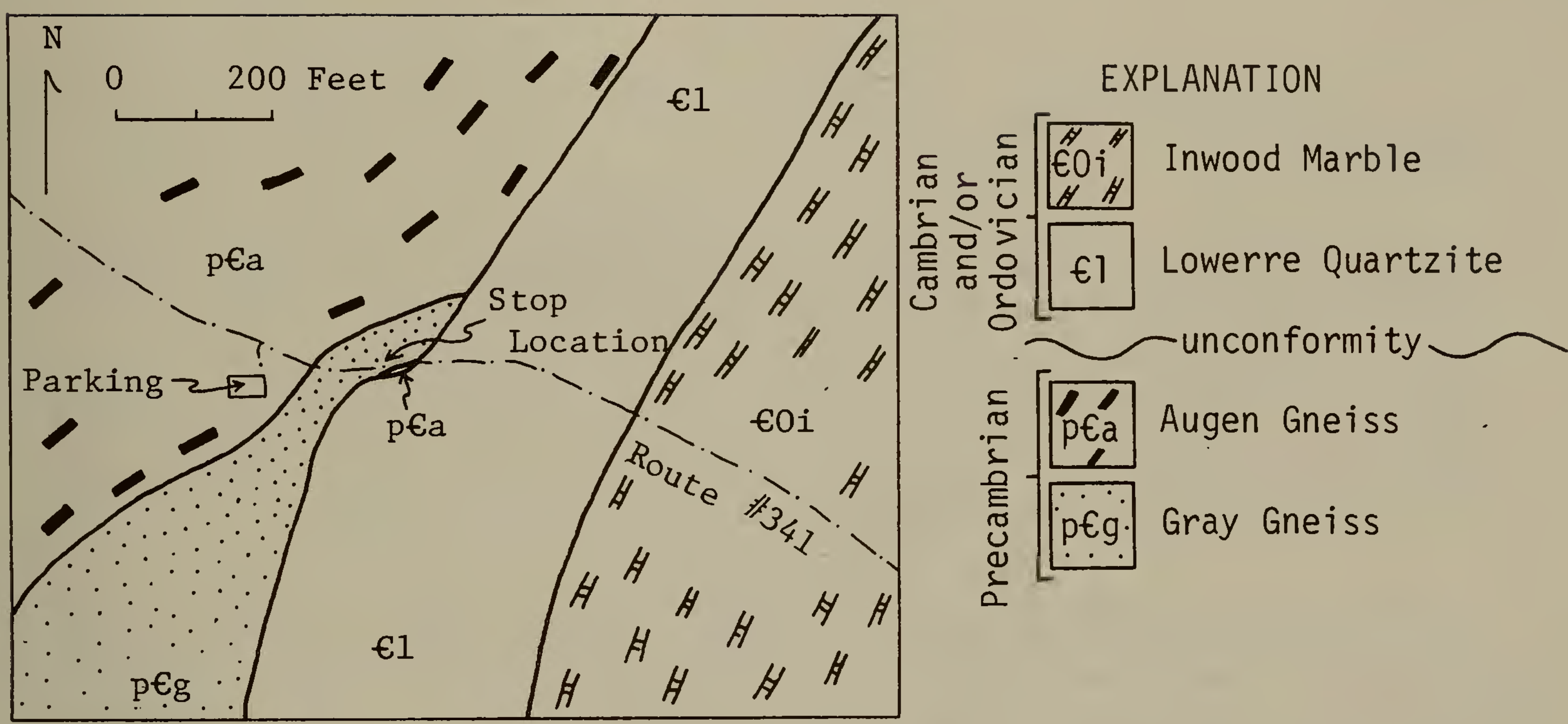


Figure 8. Geologic map of the region in the vicinity of Stop 1.

ROAD LOG

From the Hartford, Connecticut area follow Route #84 west to Route #7 in Danbury. Drive north along Route #7 to Route #341 in Kent Village.

The assembly point is the Kent School Ice Arena parking lot (Fig. 8), located on Route #341 approximately 0.6 miles west of the Route #7/#341 intersection in Kent Village.

Stop 1. Kent School Road Cut. The road cut, located along the east edge of the Housatonic Highlands (Fig. 8) is in Precambrian gneisses that are overlain unconformably by the Cambrian Lowerre Quartzite. Two Precambrian rock units, Pinkish Granitic Augen Gneiss and the Gray Gneiss, are exposed in the cut (Fig. 8). The latter consists of interlayered gray, biotite gneisses, hornblende gneisses, and amphibolite. The Augen Gneiss is also present near Stop 6 (Fig. 18A, p€a) in the core of the Bear Hill Anticline.

The Augen Gneiss is a well foliated pink and pale-pinkish gray, biotite-quartz-plagioclase-microcline augen gneiss with widely scattered concentrations of garnet. The pale-pinkish gray augen gneiss contains more plagioclase. Minor thin, dark-gray biotite gneisses with hornblende and epidote are locally interlayered with the augen gneiss.

The Gray Gneiss unit includes five main rock types, all of which are penetrated by granitic layers: well foliated, gray hornblende-biotite-quartz-plagioclase gneiss, fine-grained, siliceous, gray, biotite-plagioclase-quartz gneiss, dark-gray, garnet-hornblende-quartz-biotite-plagioclase gneiss, dark-gray biotite amphibolite, and light-gray calc-silicate rock.

The Lowerre Quartzite consists of interbedded light-brown or buff-weathering quartzite and coarse-grained conglomeratic quartzite. This is the western facies of the Lowerre Quartzite. Locally, along strike, there are interbeds of schistose quartzite and feldspathic quartzite with quartz/feldspar nodules, similar to the rocks of the eastern facies noted at Stop 6. Deeply weathered micaceous conglomeratic quartzite 3-5 feet thick is present at the base of the Lowerre and appears to be sheared. The Precambrian Augen Gneiss underlies this conglomerate.

All of the rocks have been deformed by folding and faulting. Minor folds in the Precambrian rocks represent at least two phases of deformation and at least one phase of folding is represented in the Lowerre Quartzite. Faults are prominent particularly in the gneisses and shearing is evident at the Precambrian-Lowerre contact.

Minor structural features measured at this road cut are shown on the three equal area plots in Figure 9. Structural data recorded from the Precambrian rocks on the north side of the road (Fig. 9-B) show numerous fold axes clustered about the pole to the great circle defined by poles to foliation. These are the axes of the earlier of two sets of folds present in the Precambrian here and they plunge S22E at 42° (Fig. 9-B). Trends of these fold axes are scattered from S07E to S40E, and the associated axial plane foliation strikes from N20W to N20E and dips 70°-80° easterly. The age of this folding is possibly Acadian, D_3 (Fig. 7). Foliation that is parallel or subparallel to the compositional layering, also folded by this deformation, formed during an even earlier deformation, probably Grenvillian, D_1 (Fig. 7). Poles to this foliation constitute a well defined great circle and beta maximum. Crinkles, D_4 (Fig. 7), deform both the compositional layering foliation and the axial plane foliation of the southeast plunging folds. These crinkle axes trend from S26W to S58W and plunge gently to moderately southwest (Fig. 9-B). Biotie lineation trends from S35E to N85E and plunges moderately eastward. The biotite lineation appears to be deformed by the southeast plunging folds and therefore to have formed prior to the southeast plunging folds. Several fairly good candidates for early isoclinal folds associated with the lineation and foliation are on the south side of the road. Several faults strike northeasterly and dip moderately southeast.

D_3 (Fig. 7) phase folds, which deform the compositional layering foliation and mineral lineation, have a somewhat different orientation on the south side of the road (Fig. 9-C). With the exception of one fold axis trending east-southeast, these fold axes on the south side of the road trend from S02E to S08E and plunge moderately south. Poles to the layering foliation lie on a well defined great circle, the pole to which is parallel to the axes of earlier phase minor folds (Fig. 9-C). Many faults and shear zones with associated granitic rocks are present on the south side of the road and most trend northeast to east-northeast and dip moderately to steeply southeast (Fig. 9-C).

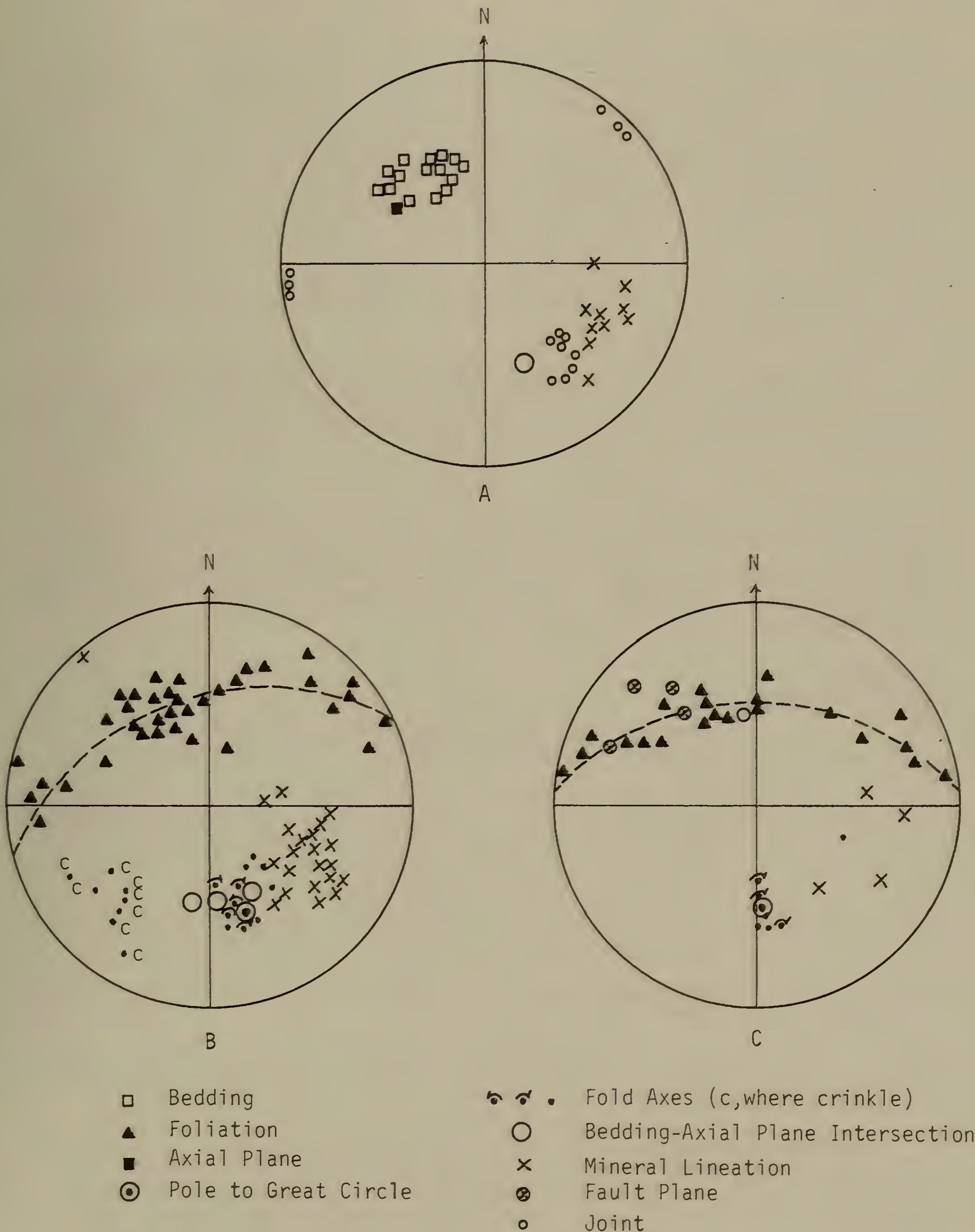


Figure 9. Equal-area diagrams summarizing structural data from the Lowerre Quartzite (A) and from the Precambrian basement north of the road (B) and south of the road (C) at Stop 1.

Bedding in the Lowerre Quartzite south of the road dips moderately southeast and strikes from N30E to N80E (Fig. 9-A). A poorly defined cleavage is locally present and is subparallel to bedding and one poorly defined minor fold has been found in the Lowerre at this locality. It was not possible to accurately measure the fold axis directly but it clearly plunges moderately southeastward. The axial plane of this fold strikes approximately N37E and dips 39SE and the intersection of the axial plane with bedding is S30E, 37SE (Fig. 9-A). Quartz and tourmaline lineations near this fold plunge S57E at 31° and S47E at 20°. Considering the orientation of features related to the deformation, it is proposed that the minor fold, cleavage and mineral lineations formed during the Taconic Orogeny, D_2 (Fig. 7).

Three prominent joint sets are present in the quartzite (Fig. 9-A). The most prominent set trends northeast and dips moderately northwest, another set trends N10W and is nearly vertical, while the third set trends approximately N45W and is nearly vertical.

A three to five foot thick zone of shearing is evident near the Precambrian-Lowerre contact. Both the Augen Gneiss and micaceous quartz conglomerate were involved in this shearing as indicated by the cataclastic texture and deep weathering of both rocks in this zone. The shearing is believed to represent minor, local shearing along the contact between rocks of contrasting ductility during folding.

Mileage Total	Interval	
0.0	-	Leave the parking lot and turn right (east) on Route #341, crossing the Housatonic River in a short distance.
0.4	0.4	Route #341/#7 intersection in Kent Village. Turn right (south) on Route #7. The Housatonic Highlands are on the west and the hills to the east are held up by allochthonous Manhattan C schists. The Housatonic River Valley is underlain by members of the Inwood Marble.
3.2	2.8	Cliffs of Precambrian gneisses are seen adjacent to the Housatonic River on the west.
4.0	0.8	Turn right (west) on Bulls Bridge Road and drive through the covered bridge.
4.2	0.2	<u>Stop 2. Bulls Bridge</u> (Fig. 10). Park in the dirt parking facility on the left side of the road, adjacent to the Housatonic River, past a small bridge.

Cambrian and/or Early Ordovician Inwood Marble Member B is unconformably overlain by Middle Ordovician Manhattan A in the Bulls Bridge area. Descend to the rock exposures in the Housatonic River on the downstream side of the open bridge, adjacent to the parking lot (Fig. 10).
<u>Station A</u> (Fig. 10) - Inwood Marble Member B here consists of massive, light-gray dolomite marble; tan-weathering siliceous dolomite marble; tan-weathering quartz granulite; and minor tan/orange-weathering calcite

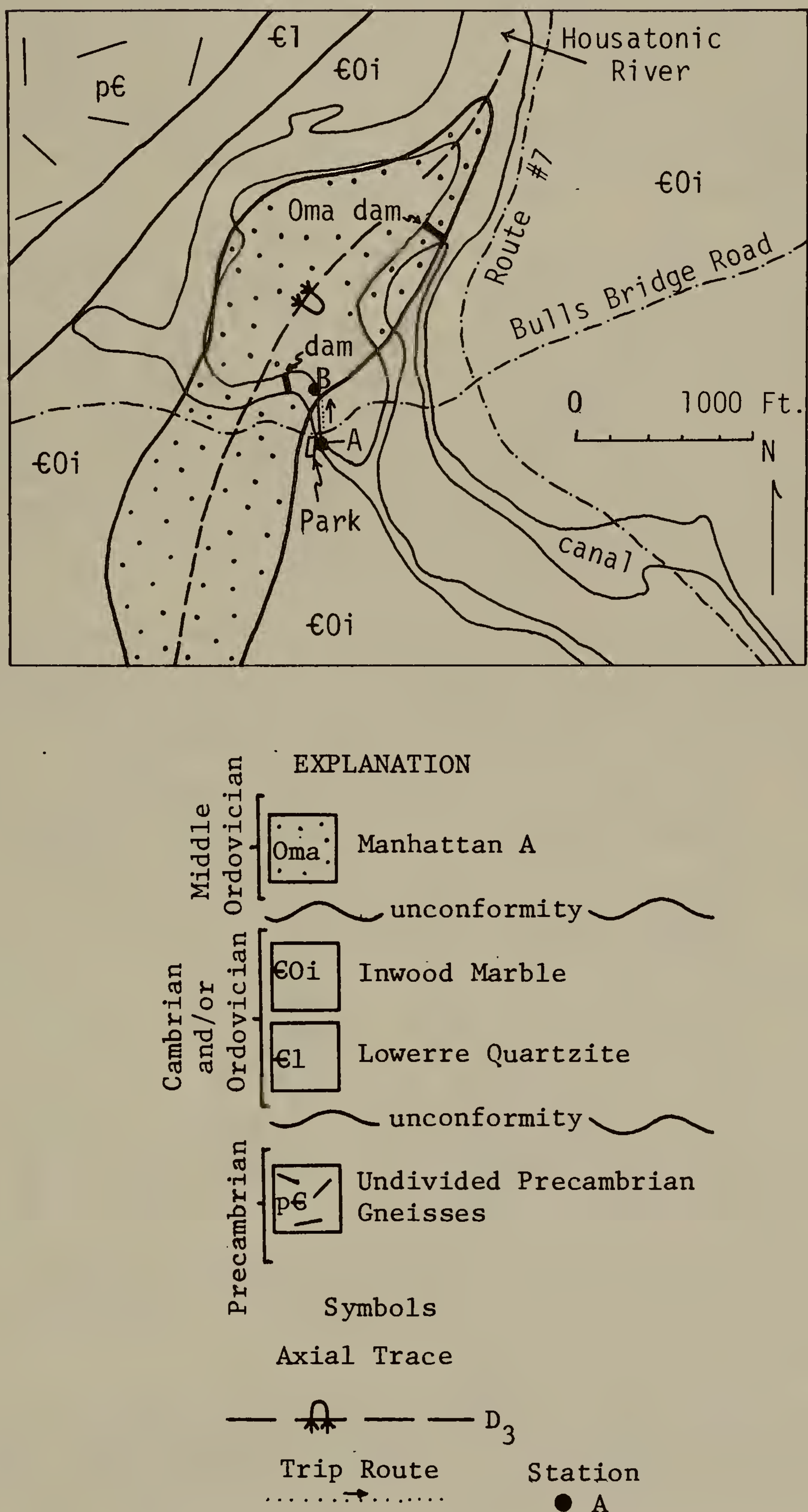


Figure 10. Generalized geologic map in the vicinity of Stop 2.

.marble. Tremolite knots up to ½ inch across are locally abundant. Station B (Fig. 10) - Walk several hundred feet upstream from the bridge, across exposures of thin, interbedded Inwood Marble. These beds contrast sharply with well foliated, rusty/sulfidic- or tan-weathering, gray to dark-gray, (muscovite)-biotite-quartz-plagioclase schist, schistose granulite, and calcareous granulite of the Granulite Member of Manhattan A. Interlayered orange/tan-weathering, well foliated, phlogopitic calcite marble is locally present. The Middle Ordovician unconformity separates Manhattan A from Inwood Marble.

The structural geology in the Bulls Bridge area is dramatically displayed by the abundant minor folds in the river exposures. Manhattan A (Station B) is in the trough of a map-scale, D_3 (Fig. 7) syncline, overturned to the west (Fig. 10). The Middle Ordovician unconformity, exposed north of the bridge at Station B, is on the eastern, overturned limb of this fold so that Middle Ordovician Manhattan A is physically beneath Cambrian and/or Early Ordovician Inwood Marble. Numerous minor D_3 folds are isoclinal to open, plunge gently south-southwest, and have axial surfaces that trend from N10E to N30E, and dip steeply northwest or southeast. Locally, these folds deform an earlier foliation, D_2 (Fig. 7), parallel or subparallel to layering.

The gentle warping of the axial trace of the large syncline (Fig. 10) is caused by D_4 (Fig. 7) folding. Minor southward plunging open folds of this stage are present at Station A with axial surfaces that trend N40W to N70W and dip moderately to steeply southwest.

4.2	-	Leave the parking facility and turn right (east) across the bridges, retracing the route on Bulls Bridge Road to Route #7.
4.4	0.2	Intersection of Route #7 and Bulls Bridge Road. If not going to Optional Stop A proceed across Route #7, continuing on Bulls Bridge Road.

Road Log For Optional Stop A

0.0 - Turn right (south) on Route #7.

1.1 1.1 Optional Stop A. Housatonic River. Park on the right side of the road and walk down the stream that crosses Route #7 at the sharp corner to the rock exposure in the Housatonic River.

The rocks at this stop display multiple deformation in the Inwood Marble, Member B. These rocks consists of thin interbedded dolomite marbles, quartz granulites, and minor calcite marble. These rock types are discussed more fully at Bulls Bridge (Stop 2).

Three phases of folding deform the rocks; D_2, D_3, and D_4 (Fig. 7). D_2 minor isoclinal folds have locally well defined axial plane foliation that trends west-northwest and dips moderately southwest or northeast. Minor fold axes plunge moderately southeast or north (Fig. 11-A).

D_2 axial plane foliation and bedding are deformed into abundant cren-

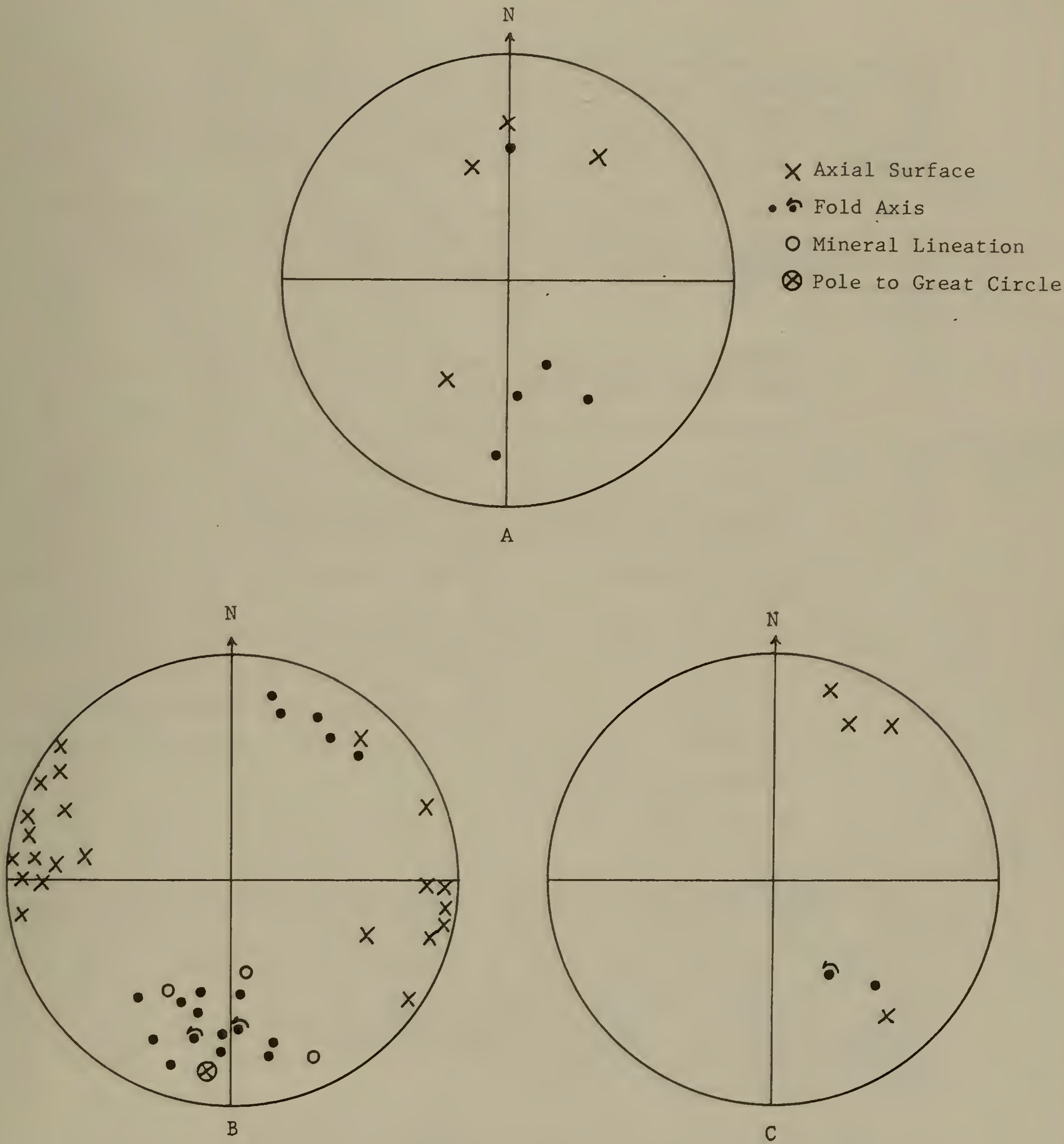


Figure 11. Equal-area diagrams summarizing structural data from the Inwood Marble at Optional Stop A, including D_2 (A), D_3 (B), and D_4 (C) events.

ulations and minor open to isoclinal folds of D_3 age. Axial surfaces trend from N24W through north to N36E and dip steeply northeast or northwest. Associated minor fold axes plunge gently to moderately north or south. The pole to the great circle defined by poles to bedding and D_2 foliation is parallel to the south plunging minor D_3 fold axes (Fig. 11-B).

D_4 axial surfaces trend northwest or northeast and dip steeply southwest or northwest, respectively (Fig. 11-C). Minor crenulation axes plunge moderately southeast. Age relations between the northwest and the northeast cleavages can not be determined and they are thought to be contemporaneous.

1.1	-	Return back to the vehicles, carefully turn around and retrace Route #7 to Bulls Bridge Road.
2.2	1.1	Turn right (east) on Bulls Bridge Road.

4.4	-	Intersection of Route #7 and Bulls Bridge Road. Proceed across Route #7, continuing on Bulls Bridge Road.
5.4	1.0	Low lying exposures of Manhattan C schist on either side of the road.
6.2	0.8	Entrance of South Kent School. Proceed along Bulls Bridge Road.
6.7	0.5	Turn left (north) into the school grounds near a small pond.
6.8	0.1	Turn right (east) at the sign indicating the direction to the boat house.
7.0	0.2	Bear left on the dirt road.

7.3 0.3 Stop 3. Hatch Pond (Fig. 12). Park in the lot adjacent to the boat house.

At this stop rocks of Manhattan C are in thrust contact with autochthonous Middle Ordovician Manhattan A. Walk on the path that starts behind the boat house, trailing the shoreline of Hatch Pond. The rock exposures on the left (west) are schists of the allochthonous Manhattan C which occur in the trough of a map-scale D_3 (Fig. 7) syncline (Fig. 12). Ascending a hill the path divides into an upper and lower trail. Walk on the lower path near the water. At this location partially buried outcrops of massive, white to gray, calcite marble and dark-gray schistose granulite of Manhattan A are exposed.

Continue along the path close to the shoreline where there are several large exposures of the Granulite Member of Manhattan A. These rocks are interlayered, well foliated to weakly foliated, tan to rusty/sulfidic-weathering, gray or dark-gray, (muscovite)-biotite-quartz-plagioclase micaceous to schistose granulites, with locally abundant thin, discontinuous quartz stringers parallel to foliation; light-gray, well foliated calcareous schist or granulite; and thin-bedded, light-gray, calcite marble.

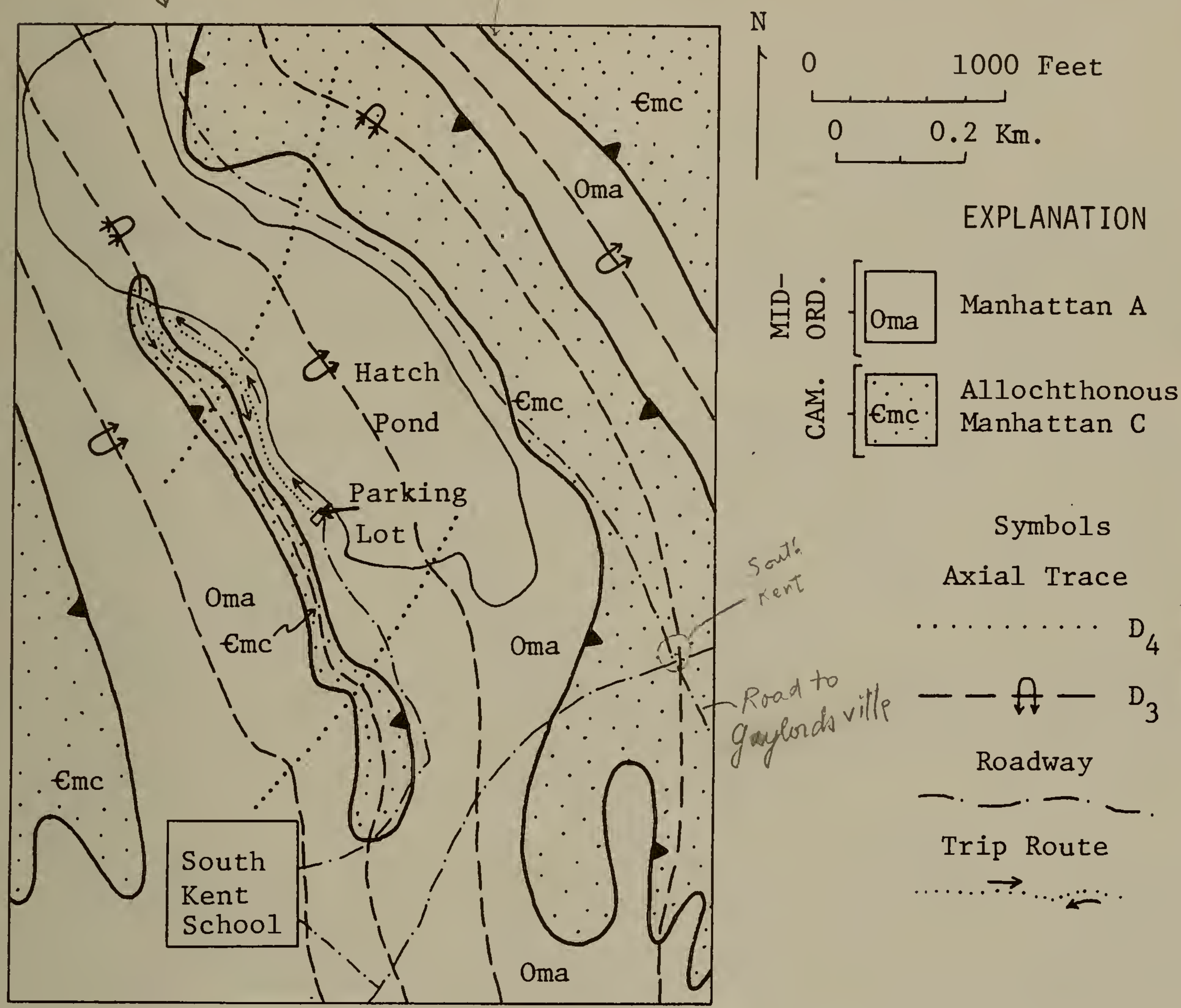


Figure 12. Generalized geologic map in the vicinity of Stop 3.

Rocks of Manhattan C occupy the the upper parts of this hill. Although not actually exposed here, the thrust separating allochthonous Manhattan C from autochthonous Manhattan A is crossed a short distance further along the path. The remaining rock exposures along the northern section of the path are in Manhattan C and are interlayered, tan or reddish tan to light-gray, garnet-sillimanite-quartz-biotite-muscovite schist and granulitic schist. The schistose layers, especially noted on higher parts of the hill, have abundant sillimanite knots, 1/8 inch across, that give the weathered outcrop surface a "warty" appearance. Thin quartz lenses parallel to foliation may be stretched pebbles. One inch thick, discontinuous glassy gray quartzite layers are locally noted. These layers are lithically reminiscent of glassy quartzite beds in the autochthonous Lowerre Quartzite (Stops 1 and 6). This supports the proposal that Manhattan C is an eastern facies equivalent of the Lowerre Quartzite that has been transported westward across the autochthon.

At this stop there is evidence for three separate phases of folding; D_2, D_3, and D_4 (Fig. 7). A structural analysis of the area was made and the data are displayed on the equal area diagram in Figure 13.

Following the emplacement of Manhattan C the rocks were deformed into isoclinal, possibly recumbent, folds, D_2, with axial planar schistosity,

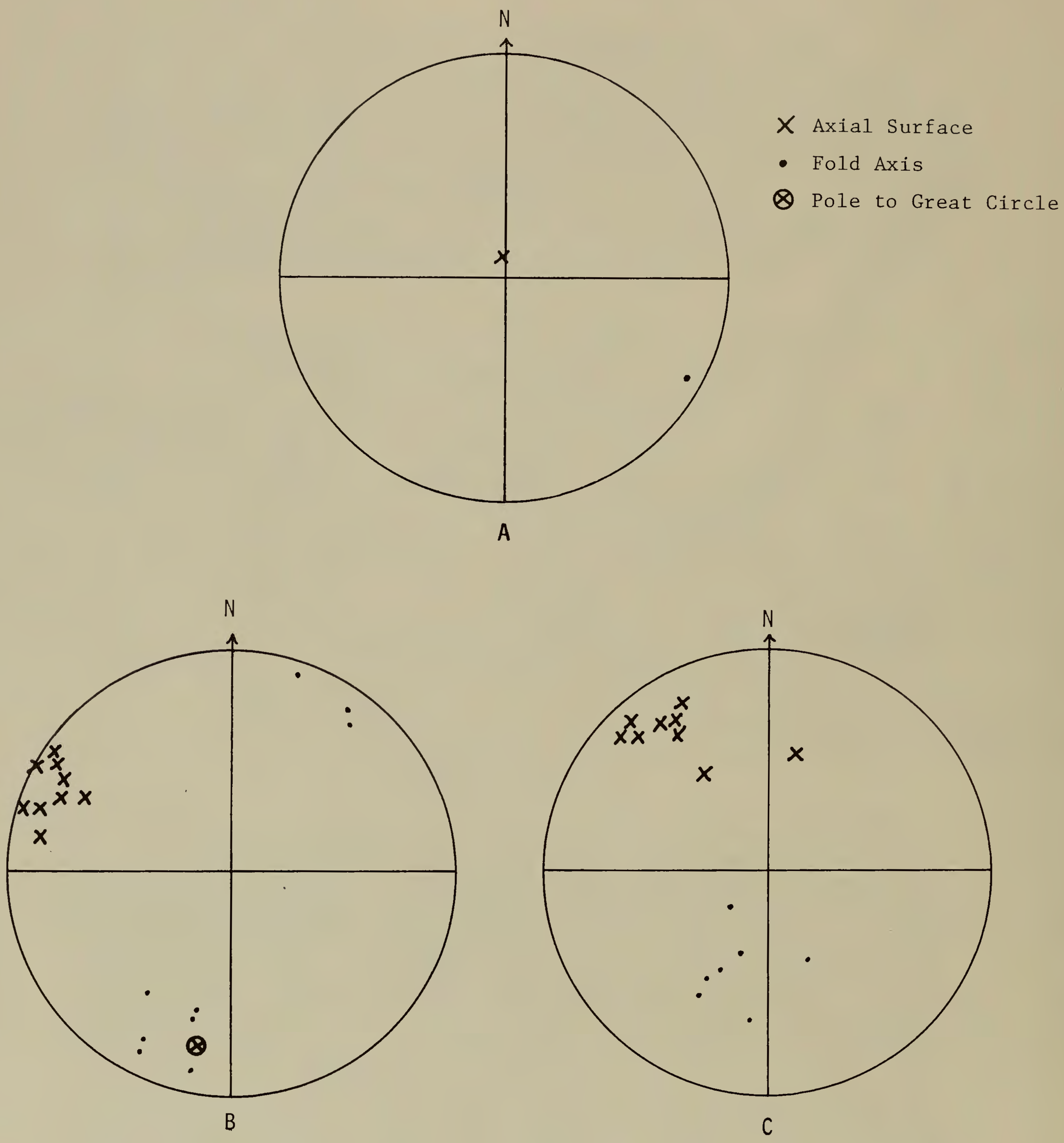


Figure 13. Equal-area diagrams summarizing structural data for Stop 3, including D_2 (A), D_3 (B), and D_4 (C) events.

the dominant planar feature in the rocks at this stop. One early minor fold is noted (Fig. 13-A) and its axial plane schistosity trends east-west, dips gently south, and has an axis plunging gently southeast. This corresponds well with the regional trend of D_2 fold axes, plunging either northwest or southeast.

Abundant D_3 minor folds and crenulations, are present and are related to the dominant map-scale folding in the Hatch Pond area (Fig. 12). These large folds, open to isoclinal and overturned to the west, have Manhattan C in the troughs of the synclines and Manhattan A in the cores of the anticlines. This stop is in the axial region of a D_3 syncline (Fig. 12). Evidence for D_3 folding consists of minor folds and crenulations that deform bedding and D_2 schistosity. These minor folds have axial surfaces that trend from N10E to N34E and dip steeply southeast and axes that plunge gently northeast or southwest (Fig. 13-B). A pole to the great circle that contains the poles of the D_2 schistosity plots in the southwest, nearly coincident with D_3 minor fold axes, indicating the effect of this later deformation on earlier axial surfaces.

Map-scale folds, D_4, having northeast axial trends deform earlier, D_3, folds in the Hatch Pond area (Fig. 12). In the rocks at this stop these D_4 folds are crenulations in the earlier schistosity having axial planes trending from N43E to N63E, dipping moderately or steeply southeast (Fig. 13-C). Crenulation axes plunge moderately southwest or southeast. One late minor fold has an axial plane that trends N78W and dips 53SW. Within the Kent area two distinct axial plane trends for the D_4 phase, northeast and northwest, are noted. Both appear to be contemporaneous, and the D_4 event is described as having a conjugate set of cleavages.

7.3	-	Walk back to the parking lot along the trail. Leave the parking lot and retrace the route back to Bulls Bridge Road.
7.9	0.6	Turn left (east) on Bulls Bridge Road.
8.2	0.3	Intersection of South Kent Road. Proceed across the intersection onto Camps Flat Road.
8.8	0.6	Geer Mountain Road on the left (north). If <u>not</u> going to <u>Optional Stop B</u>, continue along Camps Flat Road.

<u>Road Log For Optional Stop B</u>

0.0	-	Turn left (north) on Geer Mountain Road. Highlands on the east are Precambrian gneisses.
1.7	1.7	Bear right (east) on Flat Rock Road.
1.8	0.1	Majestic southward view for the next ¼ mile along Flat Rock Road.
2.4	0.6	Turn left (north) on South Road.
3.1	0.7	Turn right (east) on Route #341.
3.9	0.8	<u>Optional Stop B. Bald Hill Road Cut</u> (Fig. 14). Park along the right hand side of the road.

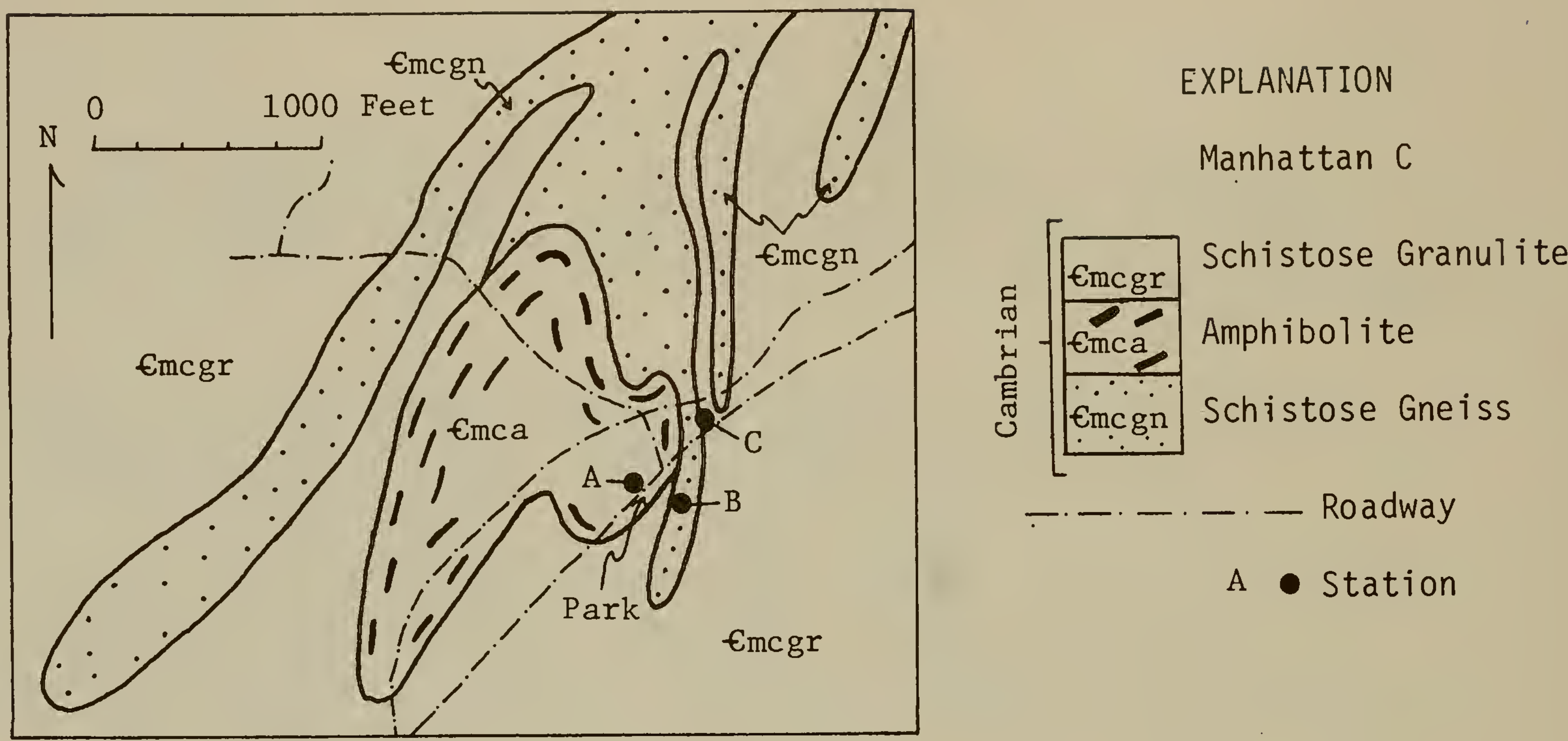


Figure 14. Generalized geologic map in the vicinity of Optional Stop B.

This long road cut exposes three mapped units of allochthonous Cambrian Manhattan C, including the Schistose Gneiss, Amphibolite, and Schistose Granulite Members (Fig. 14).

Station A (Fig. 14) - The Amphibolite Member is at the southwestern tip of the road cut. It is a dark-gray or black, well foliated to slabby amphibolite and hornblende gneiss, locally with abundant thin quartz-feldspar layers. Since this part of the road cut is in the hinge area of a map-scale, open, D_3 (Fig. 7) fold, the foliation is nearly horizontal. The amphibole lineation on foliation surfaces may be related to an earlier, D_2 event (Fig. 7).

Station B (Fig. 14) - Walk across the road to a small knob. This is the Schistose Gneiss Member and consists of well foliated, tan- to tan/gray-weathering, garnet-sillimanite-quartz-feldspar-biotite-muscovite schist and schistose granulite with abundant sillimanite knots, ¼ inch across. These knots give the weathered surface a "wart-like" appearance. Numerous thin (1/8 to 1/4 inch) quartz stringers are parallel to foliation.

Station C (Fig. 14) - Walk back across the road to examine the remaining up hill parts of the west road cut. The Amphibolite Member is in contact with schists of the Schistose Gneiss Member. Here the schists do not contain the sillimanite knots, so distinctive at Station B. Within approximately 20 feet the schists are interlayered and gradational with more massive rocks of the Schistose Granulite Member in the remaining parts of the road cut. The Schistose Granulite Member consists of the following rocks, all mutually gradational: massive, light-gray to gray, micaceous granulite; well foliated, gray, schistose granulite; tan/gray, coarse, sillimanite-mica schist with abundant 1/4 to 1/2 inch quartz/feldspar stringers or lenses parallel to foliation; and light-gray and dark-gray schistose gneiss.

The schists at the north end of the cut display abundant D_3 (Fig. 7) crenulations, plunging gently north or south, in earlier D_2 axial plane foliation. Steep slickensided fault surfaces trending nearly parallel to the roadway give evidence for late shearing.

3.9 - Turn around and retrace the same route to Camps Flat Road.

7.8 3.9 Turn left (east) on Camps Flat Road.

8.8 - Geer Mountain Road on the left (north). Proceed along Camps Flat Road.

9.6 0.8 Cross a small stream and the road becomes Meetinghouse Hill Road.

9.7 0.1 Stop 4. The Candlewood Lake Pluton at Peet Hill (Fig. 15). Pull over to the right side of the road. Do not block private driveways.

This stop demonstrates the intrusive relationship of the Ordovician Candlewood Lake Pluton to allochthonous Manhattan C, and subsequent phases of deformation affecting the rocks. Samples were collected at Station A for radiometric dating (Mose and Nagel, appended to this report). Exposures of the pluton extend from a short distance north of Stop 4 southward for several miles into the New Milford quadrangle (Fig. 1). There, it is named for Candlewood Lake. Towering rock cliffs of the granite can be seen south-southwest of Station B, on Rock Cobble Hill. Much of the area underlain by the Candlewood Lake Pluton has previously been referred to as the New Milford Massif (Rodgers, et al., 1956), considered Precambrian. Mapping has shown that the pluton intrudes autochthonous rocks ranging in age from Precambrian to Middle Ordovician and the allochthonous Cambrian Manhattan C (Fig. 3).

Station A (Fig. 15) - Follow a well defined trail, near where the small stream crosses the road, to Peet Cemetery past several large granite boulders. Since the trail ends at the cemetery, proceed north adjacent to the stream. Several outcrops of massive, tan-weathering, white dolomite marble of Cambrian Inwood Marble Member A lie along the west bank of the stream. Pass a small knob of granite adjacent to the stream, proceeding in an upstream direction toward a large hill.

The large, obvious rock exposure on this hill is of the granite of the Ordovician Candlewood Lake Pluton. The valley to the right (east) is underlain by calcite marble of Manhattan A. The stream valley on the left (west) has Inwood Marble Member A. It is known (Stop 2) that Manhattan A rests unconformably on older rocks and this unconformity is in the area between these two valleys (Fig. 15).

Ascend the right (east) side of the hill to several low lying, moss-covered outcrops. These exposures are locally of well bedded, orange/tan-weathering phologopite-calcite marble and massive, light-gray dolomite marble of the Calcite Marble Member of Manhattan A. In the lowest outcrop on the east side of the hill bedding trends approximately east-west and dips north into the hill. Within two feet of this marble exposure is the massive to weakly foliated, light-gray or tan, (muscovite)-biotite

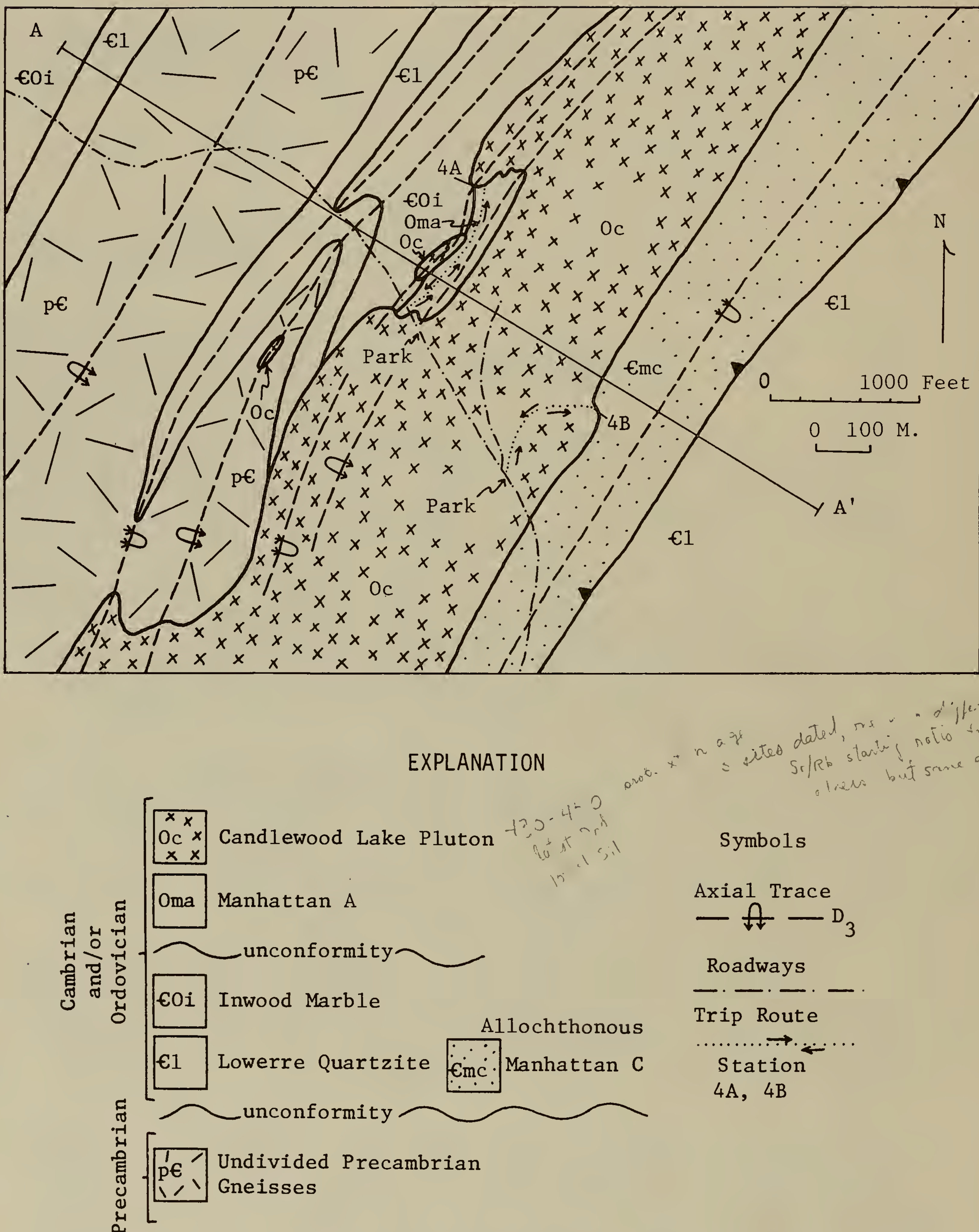


Figure 15. Generalized geologic map of the vicinity of Stop 4, indicating stations A and B at separate localities.

granite. Locally, pegatite and quartz dikes cut through the granite. The proximity of the marble to the massive granite exposure clearly demonstrates the intrusive nature of the Candlewood Lake Pluton.

Minor open folds, D_3 (Fig. 7), in the well bedded phlogopite-calcite marble have axial plane foliation trending approximately N55E, dipping steeply northwest and axes gently to moderately plunging northeast. Foliation in the granite trends N60E and dips moderately northwest, indicating that the dominant foliation in the granite at Station A is related to D_3 folding. Better evidence for the structural interpretation of the Candlewood Lake Pluton is demonstrated at Station B.

9.7 - Return to the vehicles and proceed south along Meetinghouse Hill Road.

9.9 0.2 Station B (Fig. 15) - Drive beyond the intersection with Peet Hill Road, and pull over to the side of the road. Walk up a small, bushy valley adjacent to Peet Hill Road, ascending to a large outcrop at the top of the steep slope. Manhattan C is exposed in numerous outcrops southward along this slope. An excellent exposure is located approximately 1500 feet south in a cliff adjacent to the road, and is mentioned in passing in this trip travel log.

Manhattan C at the Station B exposure is interlayered, schistose granulite and well foliated, coarse-grained, reddish tan- or gray-weathering, garnet-sillimanite-quartz-feldspar schist with locally abundant sillimanite nodules up to 1/2 centimeter across. Locally, thin quartz/feldspar stringers, up to 1/2 centimeter thick, are elongate parallel to foliation. Weakly foliated to well foliated light-gray or tanish gray, (muscovite)-biotite granite, the Candlewood Lake Pluton trucates this layering. This is the eastern contact of the granite (Fig. 15).

On close examination of this outcrop the foliation, that is the dominant planar feature in the metasedimentary rocks, penetrates the Candlewood Lake Pluton. Since the granite has been dated (Mose and Nagel, appended to this report) as Ordovician, it intruded the rocks prior to the development of the foliation during the Taconic Orogeny. This foliation is axial planar to isoclinal folds, D_2 (Fig. 7), illustrated in structure section AA' (Fig. 5) for the Kent quadrangle. There is no evidence for a contact aureole, suggesting that the granitic material injected into the schists while they were still quite hot. Sillimanite/K-feldspar grade of metamorphism was reached during the Taconic Orogeny. Thus, the pluton intruded the rocks during the Taconian deformation and at the time of its peak metamorphism.

Abundant folds and crenulations deform the granite/schist intrusive contact and the earlier foliation. The minor folds have axial surfaces trending N40E to N50E, dipping steeply northwest or southeast, and axes that plunge gently north. Figure 15 indicates several map-scale axial traces, correlated in age with these minor folds for the Stop 4 area. The geometry of the folding is displayed in structure section AA' (Fig. 16). This section shows these folds to be overturned to the west clearly de-

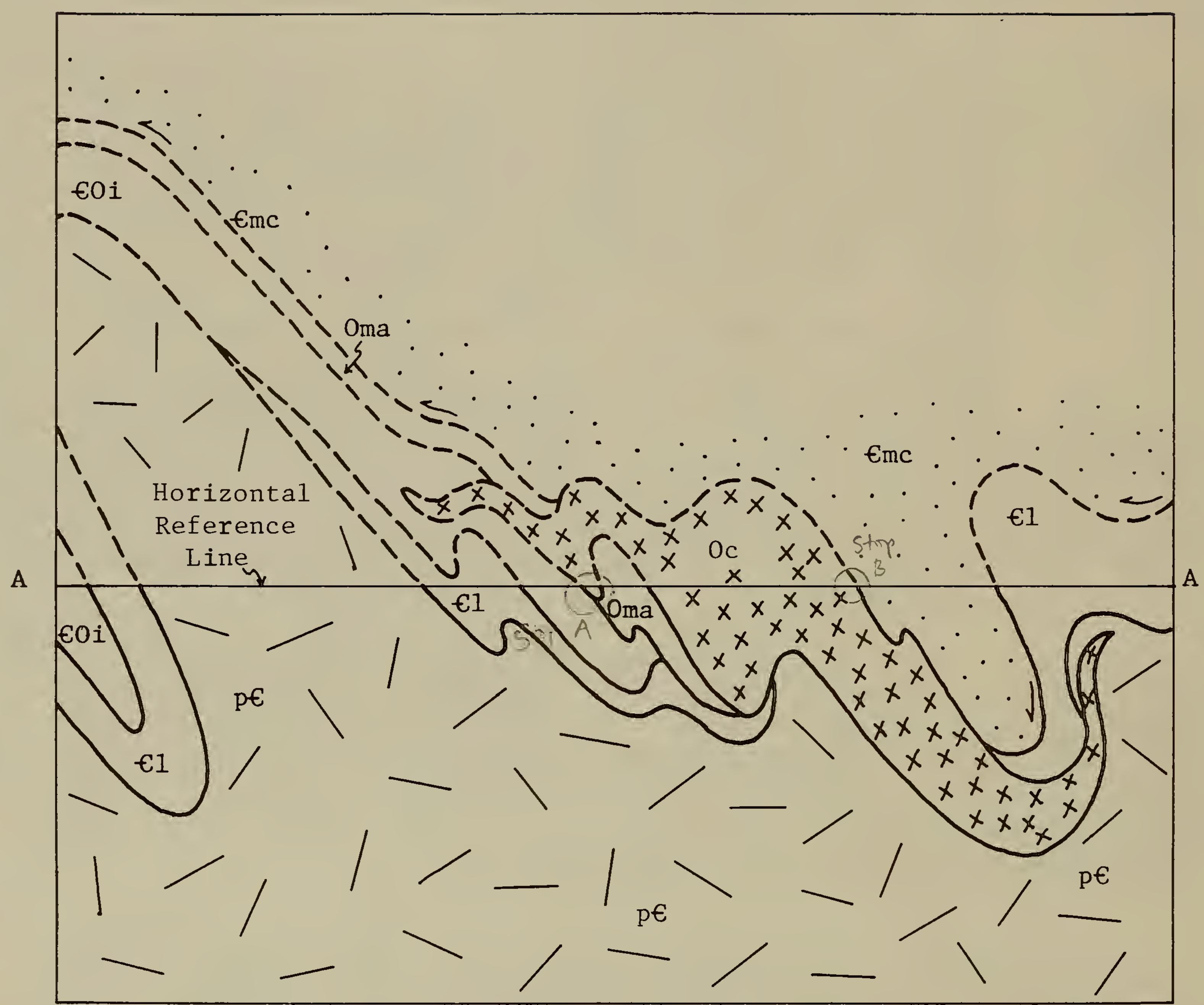


Figure 16. Structure section AA' from the geologic map for Stop 4 (Figure 15). The Ordovician Candlewood Lake Pluton (Oc) intrudes autochthonous and allochthonous rocks and is deformed by Acadian, D_3 (Figure 7), folds.

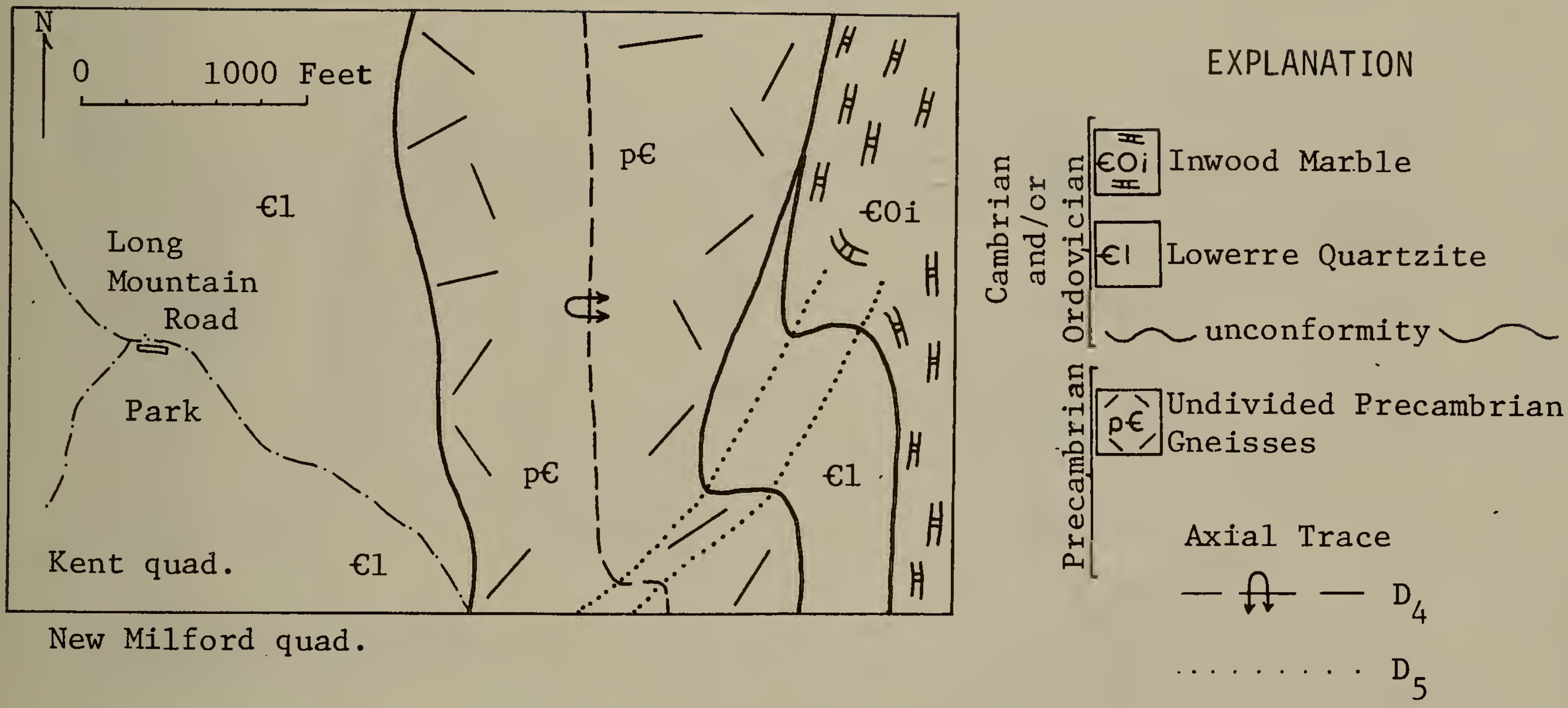


Figure 17. Generalized geologic map of the vicinity of Stop 5.

forming the Candlewood Lake Pluton, an elongate slab of varied thickness. This later folding, D_3 (Fig. 7) is interpreted to have developed during the Acadian, since it involves the deformation of the Taconian Candlewood Lake Pluton.

9.9 - Return to the vehicles and proceed south along Meetinghouse Hill Road.

10.0 0.1 Large exposure of Manhattan C schists on the left (east). Highland to the west is the Candlewood Lake Pluton.

10.6 0.6 Stop and bear right (south) onto West Meetinghouse Hill Road.

11.8 1.2 Turn right (west) on Hine Road.

13.0 1.2 Turn left (south) on Long Mountain Road.

13.6 0.6 Stop 5. Long Mountain Road (Fig. 17). Park along the right side of the road. This short stop is to examine schists of the Lowerre Quartzite. Walking southeast along Long Mountain Road numerous exposures on the adjacent hillside can be examined. The Lowerre Quartzite here consists of interlayered, coarse-grained, reddish tan-weathering, sillimanite-garnet-quartz feldspar schist with sillimanite nodules locally up to 1 centimeter across, and quartzose feldspathic schist. The schists are lithically similar to those in allochthonous Manhattan C seen at Stops 3 and 4, and at Optional Stop B. Lithic correlation supports the proposal that Lowerre Quartzite is a sedimentary facies equivalent of Manhattan C.

The dominant schistosity, axial planar to early, D_2 (Fig. 7), regional isoclinal folds, has the sillimanite nodules lying within it. The schistosity and sillimanite nodules are in turn deformed by noticably abundant crenulations with axial surfaces trending N30E to N60E and dipping steeply northwest. These minor crinkle folds display a counter-clockwise movement sense and axes that plunge gently to moderately northeast. At the map-scale these late folds, D_4 (Fig. 7), clearly deform the Acadian, D_3, Long Mountain Anticline (Fig. 17) that is cored by Precambrian Gray Biotite Gneiss.

13.6 - Return to the vehicles and proceed south along Long Mountain Road.

15.1 1.5 Turn right (south) on Aspetuck Road.

15.6 0.1 Turn left (east) back onto Long Mountain Road.

16.1 0.5 Turn right (south) on Merryall Road.

16.8 0.7 Turn left (north) on Paper Mill Road.

18.6 1.8 Stop 6. East Limb of the Bear Hill Anticline (Fig. 18A). Drive into the Pratt Education Center parking lot. Walk west along the road to the pasture entrance on the right.

This ridge, the west slope of the East Aspetuck River valley, is underlain by Precambrian rocks exposed in the core of the Bear Hill Anticline, with Cambrian Lowerre Quartzite on the lower parts of the slope (Fig. 18A). Four mappable Precambrian rock units have been defined here (Fig. 18A) and Cambrian to Middle Ordovician carbonate rocks are exposed further east in the East Aspetuck River valley. Middle Ordovician Manhattan A calcite marble occurs in the trough of the Aspetuck Syncline and rests unconformably on Lowerre Quartzite on the west and Inwood Marble on the east (Fig. 18A). A short traverse will be made here to study the Precambrian rocks and the Lowerre Quartzite.

Ascend the east slope of the ridge past low outcrops of Lowerre Quartzite to a terrace.
Station A (Fig. 18A) - The rock exposure on the east side of the terrace is the lower portion of the Lowerre Quartzite which lies unconformably on Precambrian gneisses. It consists of well foliated, reddish weathering, feldspar-mica-quartz granulite that has thin laminae (1/8 to 1/2 inch thick) of quartzite and quartzose schist interbedded with well foliated, gray- to tan-weathering, quartz-feldspar schistose granulite with nodules of quartz and feldspar (1/4 to 1/2 inch across) and minor beds of gray-weathering, massive micaceous and feldspathic quartzite.
Station B (Fig. 18A) - Walk west across the terrace to several outcrops of foliated light-pink to pink, biotite-quartz-feldspar gneiss with local pink microcline augen. The abundance of biotite and degree of development of foliation are directly related and the foliated appearance is varied because of the abundance of biotite differing from place to place.
Station C (Fig. 18A) - Walk northeast, parallel to the unconformity approximately 800 feet, past several rock exposures in the gray, biotite-hornblende gneiss and dark-gray, well foliated, amphibolite (p€ha). Both contacts of this unit (p€ha) are truncated along the unconformity at the base of the Lowerre (Fig. 18A).

Structural data were collected at this station, approximately 75 feet west of the unconformity (Fig. 18B). Two phases of minor folds are present and the earlier of these deforms a foliation parallel to compositional

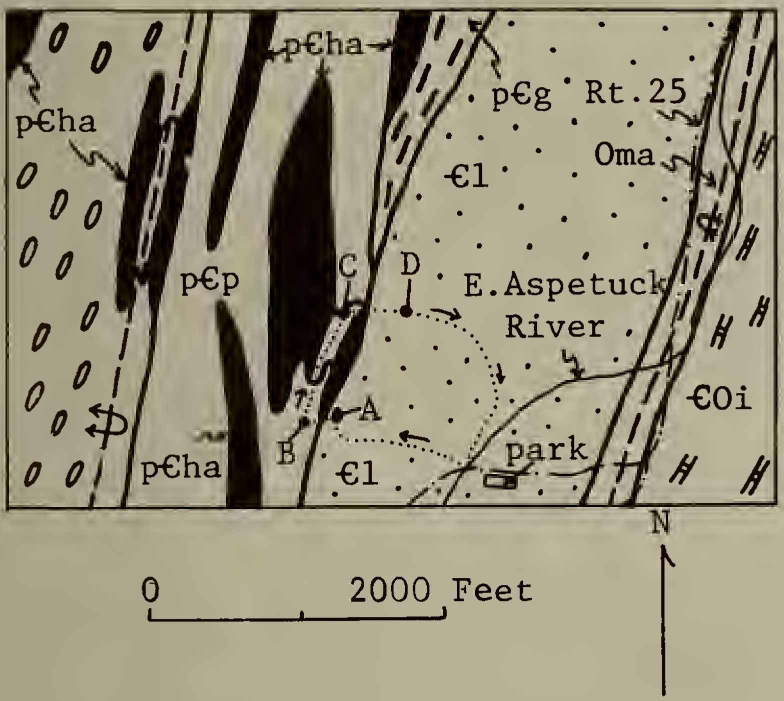
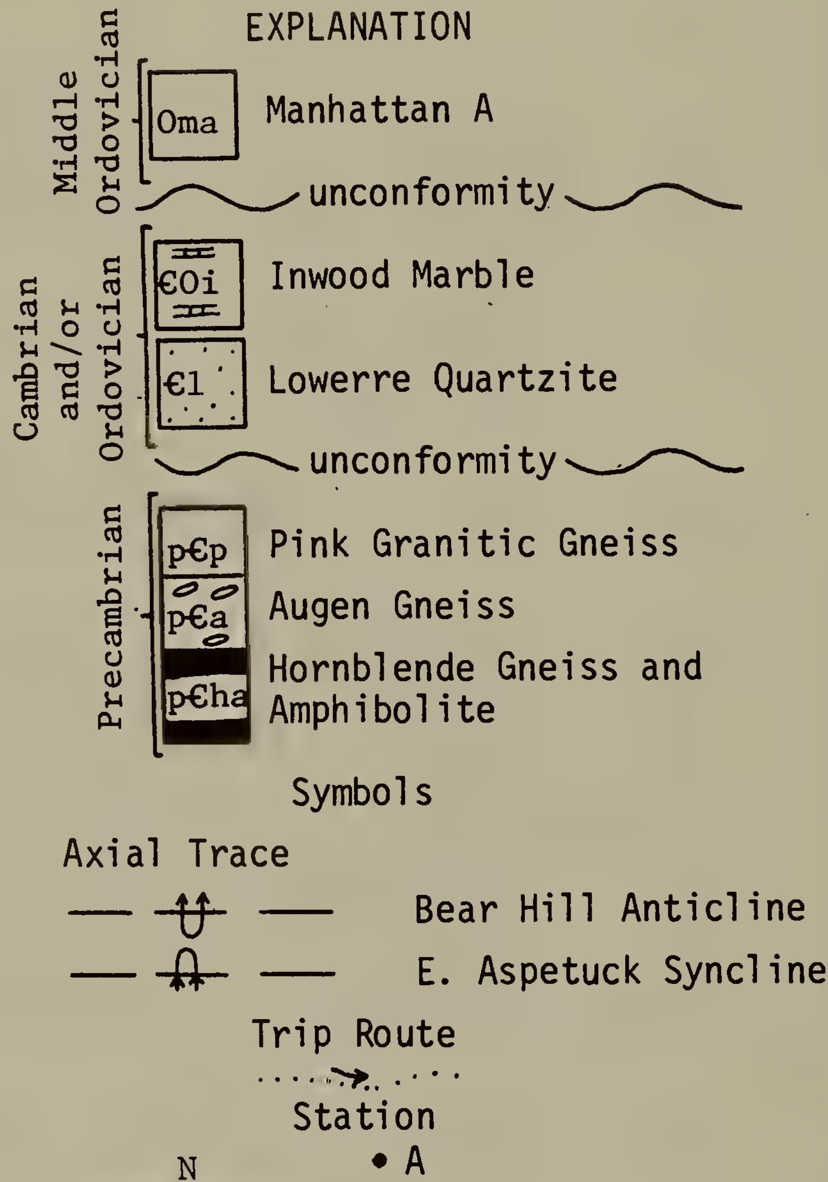


Figure 18A. Geologic map of the region in the vicinity of Stop 6.



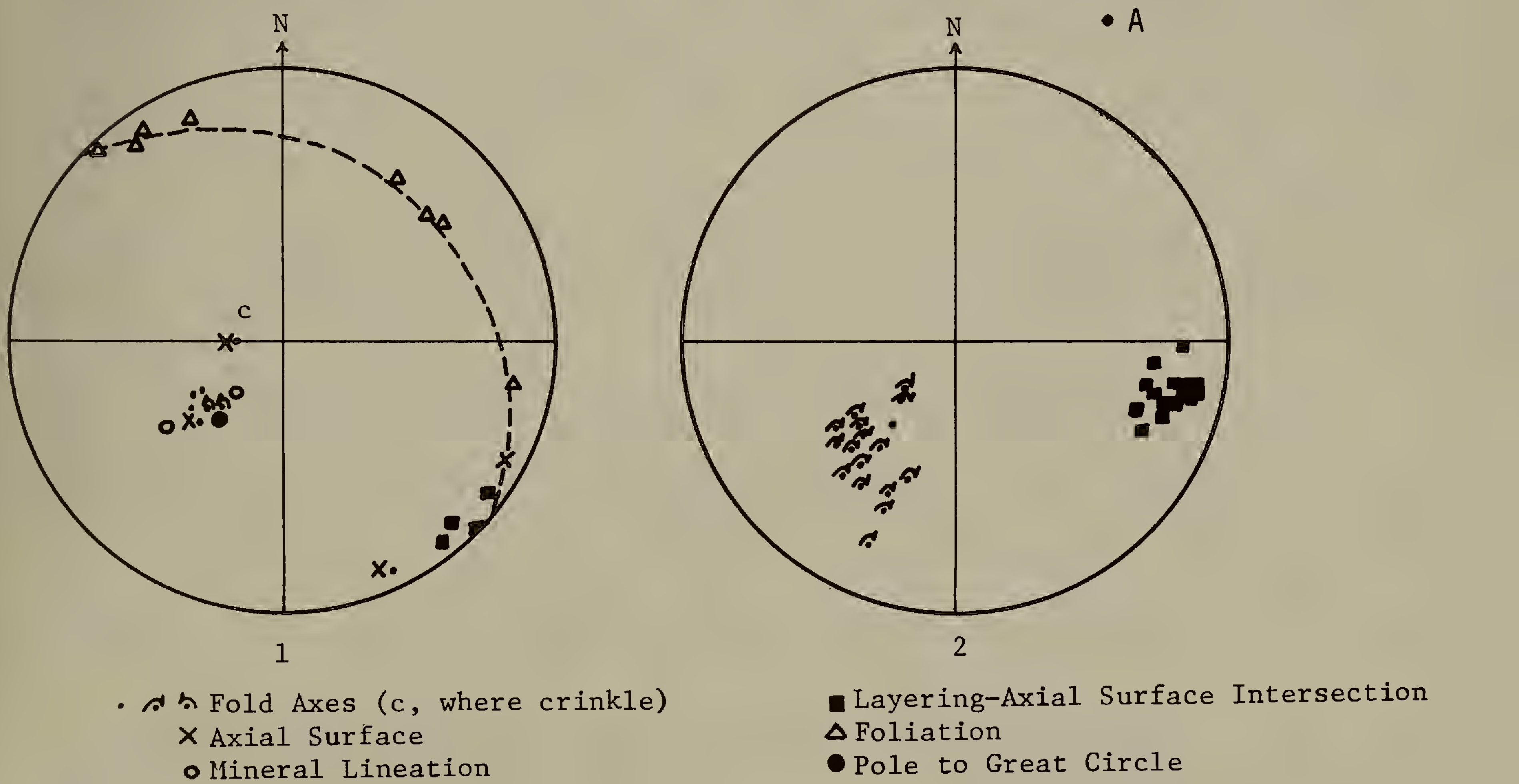


Figure 18B. Equal-area diagrams that summarize structural data from the Precambrian basement (1) and from the Lowerre Quartzite (2) at Stop 6.

layering very likely formed in the Grenville Orogeny suring a phase of folding, D_1 (Fig. 7), that preceded the early folds that are so obvious here. The axes of the minor folds have an average plunge of 50 southwesterly and some of the folds have a counterclockwise rotation sense, but the shear sense of most is indeterminate (Fig. 18B-1). The axial planes trend northeast and dip steeply northwest (Fig. 18B-1). These earlier folds, D_2 (Fig. 7) are thought to be Taconic in age and related to a large, map-scale fold, in the Precambrian units (Fig. 18A). Crinkle folds that deform earlier features at this exposure and other nearby points represent a later phase of deformation, D_3 or D_4, possibly Acadian (Fig. 7). The wide variation in the plunge of the crinkles is probably due to the varied attitude of previously folded foliation upon which the crinkles were formed.

Station D (Fig. 18A) - Proceed east crossing a small stream and ascend the small ridge where pink quartz-feldspar gneiss (p€p) is present a few feet west of the unconformity and a deeply weathered zone is in the gneiss adjacent to the unconformity. Well bedded Lowerre Quartzite, similar to that at Station A, is further east of the unconformity here. Continuing up the ridge, the exposures of quartzite in the first 50-75 stratigraphic feet are predominantly thinly laminated granulite and quartzose schist with quartz-feldspar nodules. The stratigraphic section continues upward in the Lowerre to the east, over the ridge crest, and down the hillside. The thinly laminated beds and quartzose schists are less abundant with the dominant rock type being the massive gray- to tannish gray-weathering, mica-feldspar quartzite, with local thin quartzite laminae, and feldspathic quartzite. This entire rock exposure represents the eastern, deeper water facies of Lowerre Quartzite. While feldspathic and schistose in the lower parts, cleaner interbedded quartzites are abundant higher up in the section. The massive gray or tannish quartzites are similar to those found near Stop 1 adjacent to the Housatonic Highlands.

One phase of minor folds is present in both foliation and bedding in the Lowerre (Fig. 18B-2). These folds have a clockwise rotation sense and an average plunge of 45 southwesterly. An earlier foliation, D_2 (Fig. 7) is deformed by these folds. The axial planes trend north-northeast and dip steeply northwest (Fig. 18B-2). Locally a well developed axial plane cleavage can be noted in the hinge area of these minor folds. The minor folds of this phase of deformation, which are located on the east limb of the Bear Hill Anticline (Fig. 18A), have the proper rotation sense for an anticline to the west and thus are assumed to be genetically related to the large anticline. The Bear Hill Anticline and Aspetuck Syncline (Fig. 18A) were produced during the Acadian Orogeny, D_3 (Fig. 7).

Walk down the hill to a path adjacent to the East Aspetuck River, and follow it back to Paper Mill Road.

To return to the University of Connecticut Campus continue along Paper Mill Road for 0.2 miles, turn right (south) on Routes #202/25 toward New Milford. In New Milford follow Route #7 south to Route #84 in Danbury. Travel Route #84 to Hartford, Connecticut.

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P1A-1

CHRONOLOGY OF METAMORPHISM IN WESTERN CONNECTICUT: Rb-Sr AGES

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INTRODUCTION

The Paleozoic granitic rocks of western Connecticut (Fig. 1) are muscovite plus biotite granitic rocks that are massive to foliated. They were first grouped under the name "Thomaston Granite" (Rice and Gregory, 1906; Gregory and Robinson, 1907; Agar, 1934). The type Thomaston occurs in an abandoned quarry at Reynold's Bridge south of the city of Thomaston as a small dike-like body. The Thomaston group is now known to include many granites, pegmatites and granitic gneisses and so the name "Thomaston Granite" is now considered to be a name for all the Paleozoic granitic rocks in western Connecticut.

In the past 25 years, the Thomaston has been subdivided into three granite types based on rock composition and texture. The name Nonewaug-type was introduced in the Woodbury quandrangle by Gates (1954), replacing the name Woodbury granite for this variety of the Thomaston. The name Mine Hill-type was introduced in the Roxbury quandrangle (Gates, 1959), and the name Tyler Lake-type was introduced in the Cornwall quandrangle (Gates, 1961).

The relative ages of these three types of granite is poorly known except to say that the Nonewaug-type appears post-tectonic and the Mine Hill-type and Tyler Lake-type appear to be syn- or pre-tectonic, Gates and Bradley (1952, p. 13) report that the Nonewaug-type granite in sills and dikes cut the Town Hill granite gneiss which is similar to the Mine Hill-type (see below). In the Woodbury quandrangle, Gates (1954, p. 14) reports that granite and pegmatite dikes which probably come from the Nonewaug pluton cut granitic gneiss similar to the Mine Hill-type. In the following section, it will be shown that a simple separation of pre- or syn-tectonic granite from late syn- or post-tectonic granite is useful for this area, and that while the Nonewaug-type is a good representative of the late syn- or post-tectonic granite, the Mine Hill-type is a good representative for the pre- or syn-tectonic granite. The Tyler Hill-type appears to be an example of Mine Hill-type granite that has been deformed by cataclasis. It will also be shown that the Rb-Sr ages of the granites support their relative ages as determined by field relationships.

P1A-2

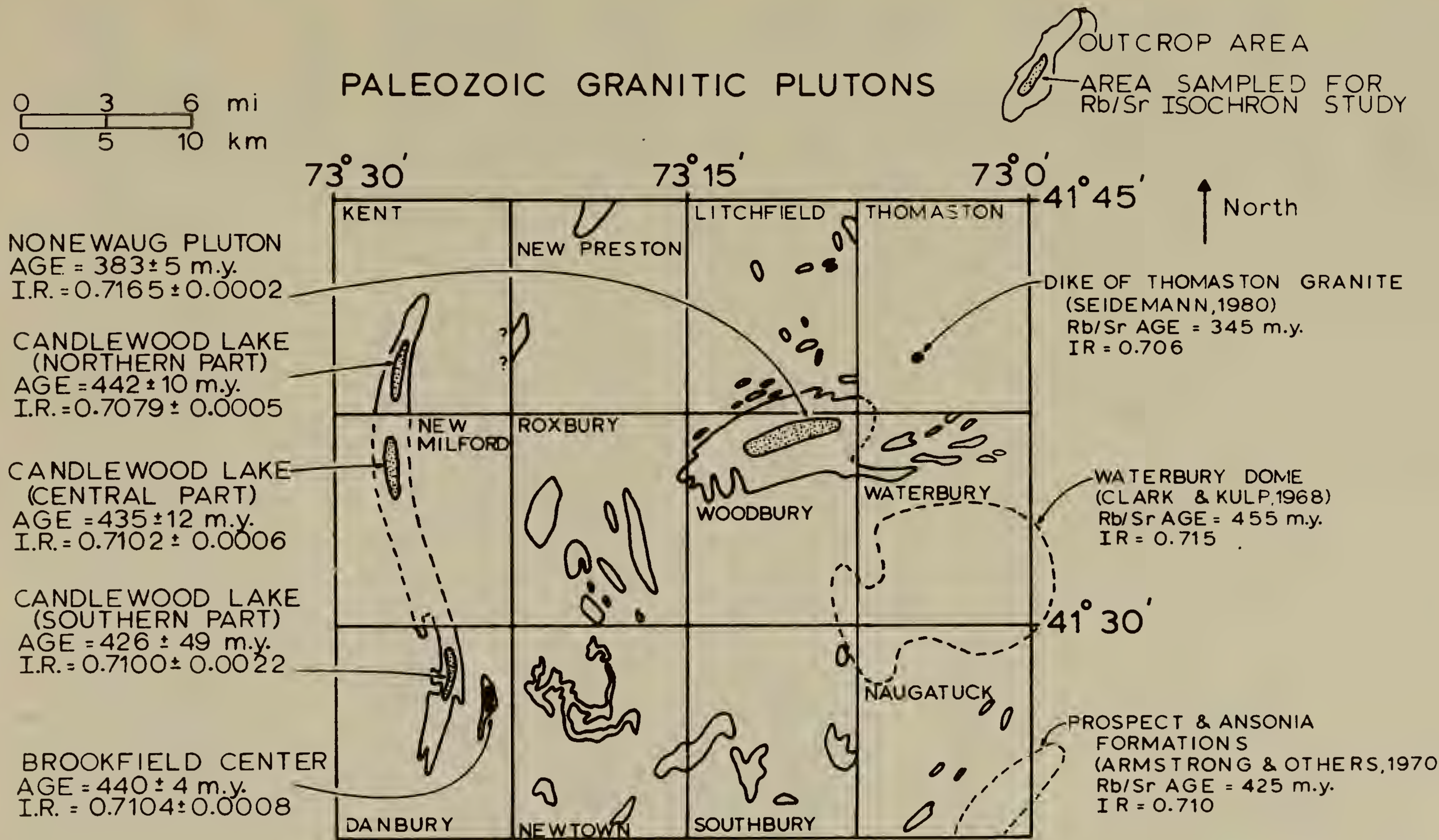


Figure 1. Quadrangle maps in western Connecticut showing the outcrop areas of granitic rocks of Paleozoic age (Kent from Jackson, 1980; New Preston from Gates and Bradley, 1952; Litchfield from Gates, 1951; Roxbury from Gates, 1959; Waterbury from Gates and Martin, 1967; Danbury from Clarke, 1958; Newtown from Stanley and Caldwell, 1976; Southbury from Scott, 1974; Naugatuck from Carr, 1960).

P1A-3

TYPES OF THOMASTON GRANITE

The Nonewaug-type granite is found mostly in the Woodbury quandrangle (Gates, 1954) but parts of the main body extend into the Litchfield (Gates, 1951, p. 11-12), Roxbury (Gates, 1959) and Waterbury (Gates and Martin, 1967, p. 26) quadrangles. Similar rock has been identified in the Torrington (Martin, 1970, p. 41-44), Newtown (Stanley and Caldwell, 1976, p. 38) and New Preston (Gates and Bradley, 1952, p. 12-14) quandrangles.

The characteristics of the granite are as follows:

1. It is an unfoliated granite which shows no cataclasis and which shows textural layering. The layers are from about 1 cm to 1 m thick and are composed of fine-grained to pegmatitic material. Sometimes the granite shows a "patchy texture" in which finer-grained material is surrounded by pegmatitic material.

2. It contains graphic granite crystals which are about 1 to 150 cm in diameter (most are 4 - 10 cm) and which commonly occur as layers or isolated crystals (plum pudding texture) in a fine-grained matrix. The graphic granite is mostly intergrowths of microcline and quartz, but sometimes of plagioclase and quartz, especially near plumose muscovite. The outer parts of the graphic granite crystals usually contain poikilitically included patches of fine-grained granite.

3. It contains plumose muscovite, an intergrowth of muscovite and quartz, which occurs in a matrix of fine-grained granite, and only in areas where graphic granite is present. The muscovite plumes are megascopic and up to 40 cm long (Gates, 1954, p. 15) or they are microscopic (Martin, 1970, p. 41).

4. It is composed of sodic plagioclase and microcline (plagioclase/microcline ratio is greater than 1), quartz, muscovite and biotite (muscovite/biotite ratio is greater than 1).

5. Xenoliths of country rock in the granite and roof pendants appear to not have been rotated (Martin, 1970, p. 41; Gates, 1951, p. 12).

The Nonewaug-type granite is generally thought to be a post-tectonic intrusion which is generally concordant with its host rock but shows local discordance and crosscutting dikes. It will be proposed, based on isotopic evidence, that the pegmatitic material, graphic granite and plumose muscovite result from late-stage infusions of alkali-rich fluids. This would agree with Gates (1954, p. 18) who suggested that the "patchy texture", porphyroblastic graphic granite and plumose muscovite are related to the activity of interstitial liquid in zones of relatively low pressure caused by structural activity during emplacement of the pluton.

The Mine Hill-type granite is found mostly in the Roxbury quandrangle (Gates, 1959), but granite gneiss of the Mine Hill-type has also been found in the Kent (Jackson, 1980, p. 42-44), New Preston (Gates and Bradley, 1952, p. 12-14), Litchfield (Gates, 1951, p. 12), Woodbury (Gates, 1954, p. 13-15), Waterbury (Gates and Martin, 1967, p. 26-28), Danbury (Stanley and Caldwell, 1976, p. 16-17; Clarke, 1958, p. 38-41), Newtown (Stanley and Caldwell, 1976, p. 16), Southbury (Scott, 1974, p. 26-27) and Naugatuck (Carr, 1960, p. 18-19) quandrangles.

The characteristics of the granite are as follows:

1. It is a foliated fine-medium grained granite gneiss with mineral segregation in the form of coarse muscovite on the foliation planes. Some layers are coarser than others, but none are pegmatitic.

2. It locally shows a small amount of cataclasis, and replacement of microcline by plagioclase is common.

3. It contains no graphic granite or plumose muscovite.

4. It is composed of sodic plagioclase and microcline (plagioclase/microcline ratio is greater than 1), quartz, muscovite and biotite (muscovite/biotite ratio is greater than 1).

The Mine Hill-type granite is thought to be a pre- or syn-metamorphic granite gneiss which had little metamorphic effect on its host rocks. It is generally concordant with the host rock, but produced cross-cutting dikes.

The Tyler Lake-type granite is found mostly in the West Torrington (Gates and Christensen, 1965, p. 30-31) and Cornwall (Gates, 1961, p. 26-27) quandrangles, though a small part of this pluton extends into the Torrington quandrangle (Martin, 1970, p. 29-41). Similar rock has been found in the New Preston quandrangle (Gates and Bradley, 1952, p. 12-13).

The characteristics of this granite are as follows:

1. Its texture ranges from massive to gneissic. It is a fine to medium- grained granite that is locally pegmatitic. The pegmatite occurs in parallel layers a few cm thick or as irregularly shaped patches.

2. It shows extensive cataclasis in which the felsic minerals are bent, curved, broken and granulated, and large megacrysts of quartz, microcline and plagioclase are set in a fine-grained matrix.

3. It contains no graphic granite, plumose muscovite, or muscovite-rich foliation planes.

4. In areas where strong cataclasis is exhibited (Tyler Lake area: Gates, 1961, p. 26; Gates and Christensen, 1965, p. 30), it is composed of sodic plagioclase and microcline (plagioclase/microcline ratio is less than 1), quartz, muscovite and biotite (muscovite/biotite ratio is about 1). However, in other areas of weaker cataclasis (Torrington area: Gates and Christensen, 1965, p. 30; Martin, 1970, p. 40), the rock composition is similar to that of the Mine Hill-type granite.

The Tyler Lake-type granite is generally thought to be a syn-tectonic intrusion which had little metamorphic effect on its host rocks. It shows discordant relationships along its border. In areas of relatively little cataclasis, it is similar to the Mine Hill-type granite gneiss.

Rb-Sr STUDY: TECHNIQUE

Samples were collected from granite gneiss, locally known as the Candlewood Lake granite gneiss and the Brookfield Center granite gneiss in the Kent, New Milford and Danbury quandrangles (Fig. 1). Samples were also collected from the Nonewaug-type granite in the Woodbury and Waterbury quandrangles (Fig. 1). Sample locations are given in Appendix 1.

The Rb-Sr isotopic analyses were conducted using the process described in Ellwood and others (1980). The half-life for the radiometric decay of ^{87}Rb is 4.89 x 10^{-10} years (decay constant is 1.42 x 10^{-11} yr^{-1}). The isotopic data are given in Appendix 2.

The Rb-Sr ages and initial $^{87}Sr/^{86}Sr$ ratios on the isochron diagrams were calculated using the regression treatment of York (1966). The one-standard-deviation experimental error in $^{87}Rb/^{86}Sr$ was calculated to be 2 percent; the one-standard-deviation experimental error in $^{87}Sr/^{86}Sr$ was calculated to be 0.05 percent. These error estimates were derived from an examination of duplicate analyses done over the past seven years. The errors assigned to the reported isochron ages and initial $^{87}Sr/^{86}Sr$ ratios are given at the 68 percent confidence level (1 sigma). Visual examinations of the fit of the Rb-Sr data to isochron lines are given in Figures 2-6. The data on the isochron diagrams are presented as 2 sigma error boxes (center of box ± 4% for $^{87}Rb/^{86}Sr$ and 0.10% for $^{87}Sr/^{86}Sr$).

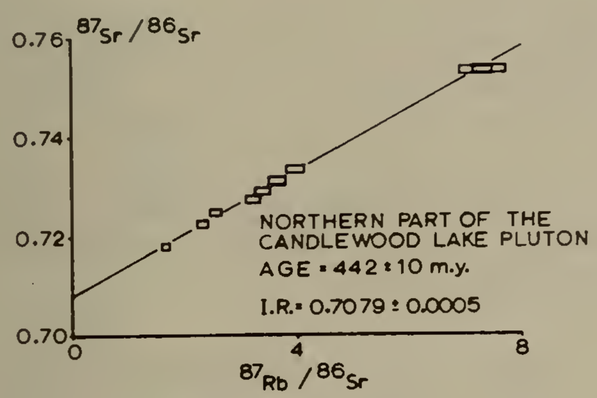
Rb-Sr STUDY: RESULTS

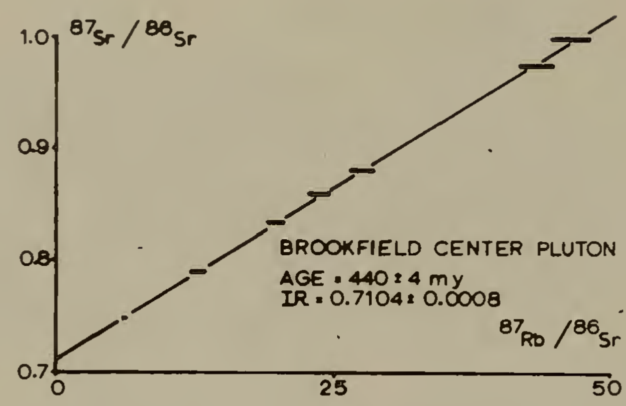
The granitic gneiss that is locally known as the Candlewood Lake pluton in the Kent, New Milford and Danbury quandrangles was studied in three areas (Fig. 1; App. 1).

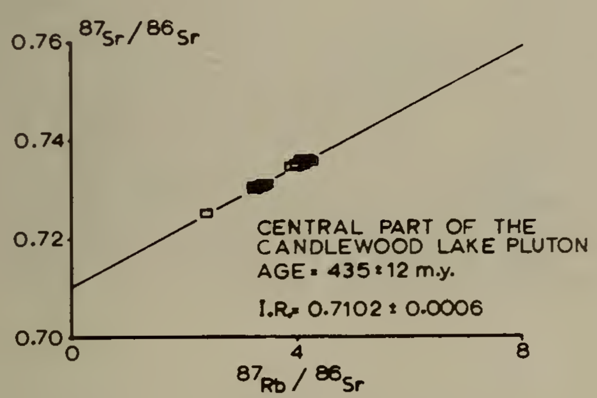
	AGE	INITIAL $^{87}Sr/^{86}Sr$
Northern Part of the Pluton (Fig. 2)	442 ± 10 m.y.	0.7079 ± 0.0005
Central Part of the Pluton (Fig. 3)	435 ± 12 m.y.	0.7102 ± 0.0006
Southern Part of the Pluton (Fig. 4)	426 ± 49 m.y.	0.7100 ± 0.0002

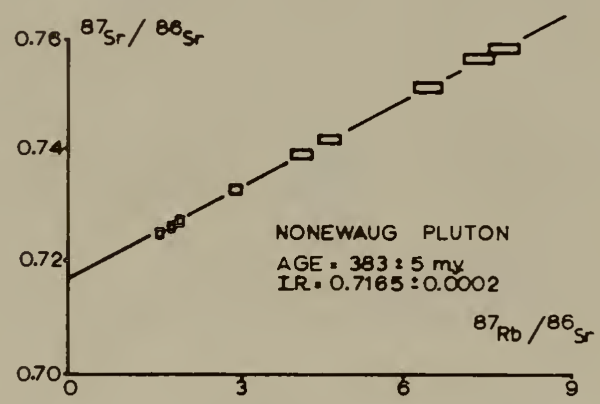
The granite gneiss that is locally known as the Brookfield Center pluton yielded an age of 440 ± 4 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7104 ± 0.008 (Fig. 5). It seems reasonable to conclude that the Candlewood Lake and the Brookfield Center plutons were both emplaced at some time between 435 and 445 m.y. ago with an initial $^{87}Sr/^{86}Sr$ ratio of about 0.710.

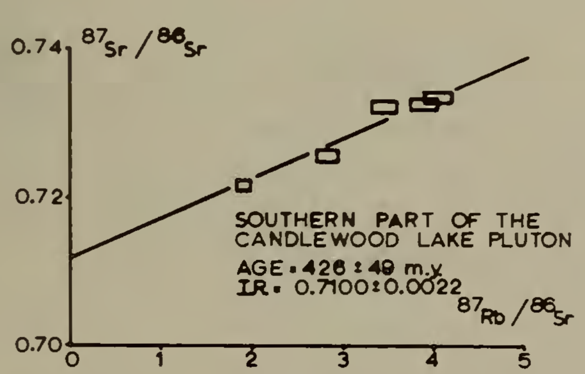
The granite that is locally known as the Nonewaug pluton in the Woodbury and Waterbury quandrangles was studied with care to note the petrography of the collected samples. As mentioned earlier, several texturally unusual varieties occur in the pluton. These include pegmatitic material, graphic granite and plumose muscovite. Samples which exhibited these properties as well as samples which did not were collected for the Rb-Sr study and the sample properties were noted (App. 3) when the data were plotted on an isochron diagram. It became clear that the texturally unusual samples did not yield a linear array on an isochron diagram, and that the samples which were composed of fine to medium-grained granite did yield a linear array. It was concluded that the texturally unusual samples probably owe their textures to the activity of interstitial liquids existed at a time when the pluton was mostly crystallized so the liquids could not chemically (and isotopically) mix with most of the pluton. The samples of Nonewaug-type granite which do not show pegmatites, graphic granite of plumose muscovite in the immediate vicinity of the sample site yield an isochron age (Fig. 6) of 383 ± 5 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7165 ± 0.0002 (an isochron generated by all the samples yields an age of 350 ± 31 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7189 ± 0.0016).











Figures 2-6. Rb-Sr isochron diagrams.

CONCLUSIONS

The granites and granite gneisses of western Connecticut have been grouped under the name Thomaston granite. This group has been subdivided into the Mine Hill-type which is a granite gneiss that is probably a pre- or syntectonic granite, the Tyler Lake-type which is probably the Mine Hill-type that is cataclastically deformed, and the Nonewaug-type that is probably a syn- or post-tectonic granite.

The granite gneiss in the Kent, New Milford and Danbury quandrangles is the Mine Hill-type and yields an age of about 445 to 435 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of about 0.710. The Nonewaug-type granite yields an age of about 390 to 380 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of about 0.716.

The other available age determinations from this area yield similar ages. Rb-Sr data from the foliated Prospect and Ansonia formations by Armstrong and others (1970) yield an age of about 425 m.y. (age recalculated using the new ^{87}Rb half-life estimate of 48.9 b.y.). Although the origin of the Prospect and Ansonia are in doubt, Carr (1960, p. 17-19) favors a pre- or syn-metamorphic igneous origin for both units. The possibility that the Prospect and Ansonia are in some way related to the pre- or syn-metamorphic Candlewood Lake pluton is suggested by the identical age and initial $^{87}Sr/^{86}Sr$ ratio for these rocks.

The only other Rb-Sr age determination on whole-rock samples comes from the Waterbury Formation, where Clark and Kulp (1968) determined an age of about 455 m.y. and a high initial $^{87}Sr/^{86}Sr$ ratio. As pointed out by Scott (1974, p. 14), the interpretation of this age is unclear, and is presently thought to be either the time of Waterbury Formation deposition or metamorphism.

There is one age determination from this area which was obtained using the Rb-Sr whole-rock plus muscovite (two-point isochron) technique. Seidemann (1980) determined the age using a sample from a "Thomaston Granite" unfoliated dike. The age, at about 345 m.y., is similar to the age obtained from the post-tectonic Nonewaug pluton reported in this study.

It is interesting to note that all the plutonic rocks in this area have relatively high initial $^{87}Sr/^{86}Sr$ ratios. High initial ratios such as these have long been known to be characteristic of plutons derived from the melting of ^{87}Rb enriched rock such as the continental crust. Figure 7, a plot of initial $^{87}Sr/^{86}Sr$ ratios vs the time of crystallization, shows that there appears to be a linear relationship between the initial ratios and the

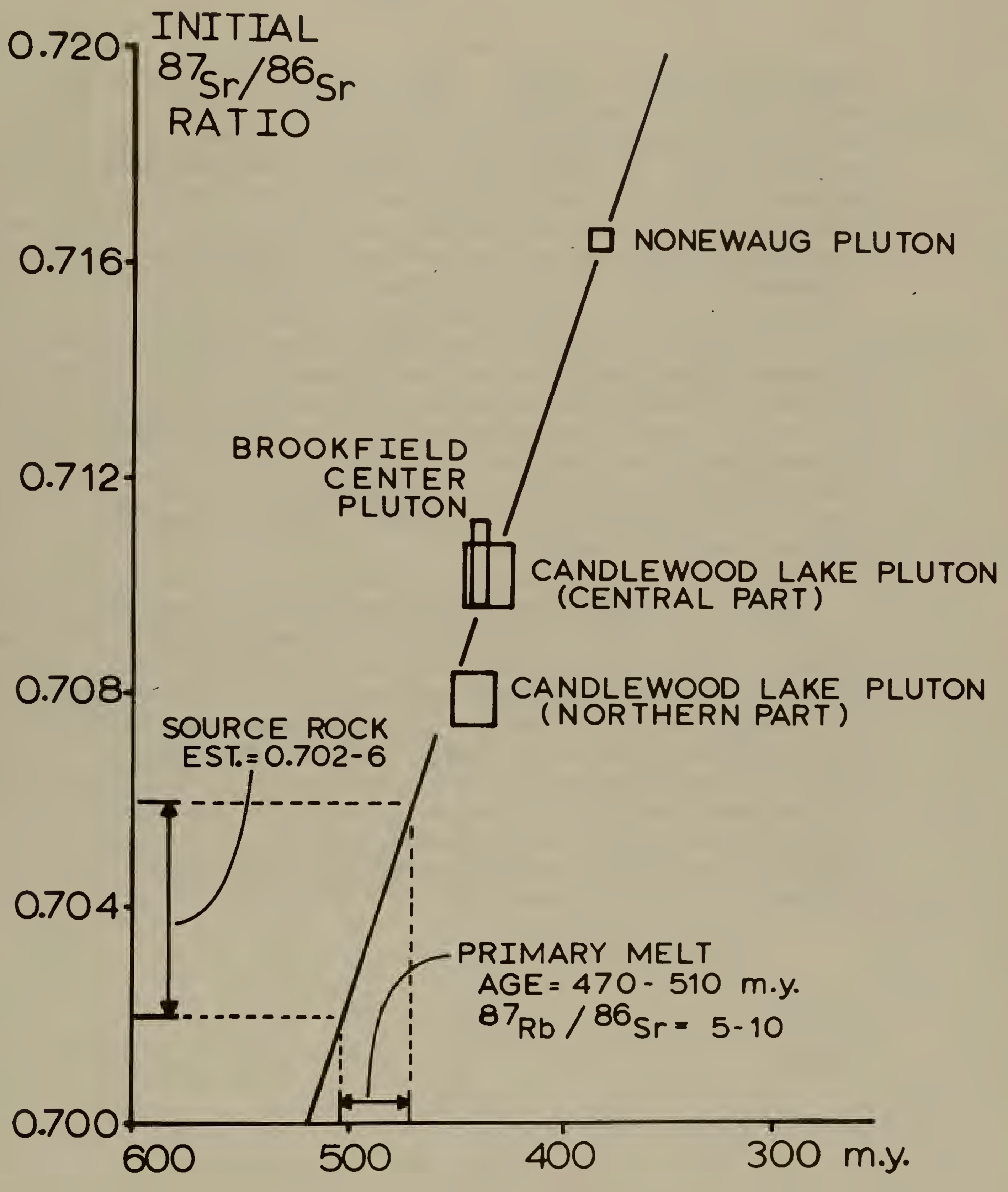


Figure 7. Initial $^{87}Sr/^{86}Sr$ ratio vs age of crystallization for plutons in western Connecticut that have been precisely dated by the Rb-Sr whole-rock technique. The slope of the best-fit line corresponds to the increase in $^{87}Sr/^{86}Sr$ that could be produced in a "primary melt" with a $^{87}Rb/^{86}Sr$ ratio of about 5 to 10.

crystallization times. Such a relationship could be explained in two ways. In the first model, these granites in western Connecticut were initially formed by partial melting at about 490 (± 20) m.y. ago at some depth greater than their present crustal level. Fractions of this "parent magma" are thought to have moved upward prior to, during, and after the recrystallization which produced the metamorphic rocks now exposed at the surface. The viability of this model, which calls for a long interval (from about 490 m.y. to about 380 m.y.) during which the granite remained liquid at a depth greater than the present erosional level, is presently unclear. The alternative model is one in which granitic melts are repeatedly generated by pre-, syn- and post-metamorphic melting events. The viability of this model seems equally unclear. Perhaps future studies will reveal the real process which formed these Paleozoic granitic rocks of western Connecticut.

The major metamorphic event which recrystallized this area is probably bracketed in time by the crystallization ages of the granite gneiss and the massive granite. If this is true, the Rb-Sr ages reported in this study indicate that the metamorphic event occured between about 440 and 380 m.y. ago, an interval which corresponds to the time between the end of the Ordovician and the beginning of the Devonian. Additional studies on other examples of the Mine Hill-type, Tyler Lake-type, and Nonewaug-type may eventually better define the event which recrystallized the sedimentary and volcanic rocks of western Connecticut.

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Appendix 1. Sample locations in western Connecticut.

	Quadrangle	Latitude			Longitude		
Candlewood Lake- northern part							
NM 11	Kent	41°	37'	52"	73°	27'	21"
NM 12	Kent	41	37	53	73	27	22
NM 13	Kent	41	37	54	73	27	23
NM 14	Kent	41	37	55	73	27	23
NM 15	Kent	41	37	55	73	27	24
NM 16	Kent	41	37	52	73	27	24
NM 17	Kent	41	37	52	73	27	24
NM 18	Kent	41	40	40	73	26	33
NM 19	Kent	41	40	40	73	26	33
NM 20	Kent	41	40	34	73	26	37
Candlewood Lake- central part							
NM 1	New Milford	41°	37'	00"	73°	28'	00"
NM 2	New Milford	41	37	00	73	28	00
NM 3-10	New Milford	41	35	11	73	27	42
Candlewood Lake- southern part							
RA 4	Danbury	41°	27'	35"	73°	25'	17"
RA 5	Danbury	41	29	8	73	25	45
RA 6	Danbury	41	29	7	73	25	43
RA 7	Danbury	41	29	12	73	25	44
RA 8	Danbury	41	28	52	73	25	23
Brookfield Center							
RA 1	Danbury	41°	27'	35"	73°	23'	12"
RA 3	Danbury	41	28	2	73	23	33
RA 12	Danbury	41	28	6	73	23	25
RA 13	Danbury	41	28	10	73	23	26
RA 14	Danbury	41	27	35	73	23	25
RA 15	Danbury	41	27	55	73	23	23
RA 16	Danbury	41	28	3	73	23	10
Nonewaug Pluton (* = used in isochron)							
NON 11	Woodbury	41°	36'	35"	73°	10'	58"
NON 12*	Woodbury	41	36	33	73	10	55
NON 13*	Woodbury	41	36	35	73	10	48
NON 14*	Woodbury	41	36	36	73	10	46
NON 15*	Woodbury	41	36	38	73	10	47
NON 16*	Woodbury	41	36	39	73	10	49
NON 17*	Woodbury	41	36	37	73	10	40
NON 18*	Woodbury	41	36	59	73	10	41
NON 19	Woodbury	41	36	59	73	10	35

Appendix 1. continued.

	Quadrangle	Latitude	Longitude
Nanewaug Pluton (* = used in isochron)			
NON 21	Woodbury	41° 36' 57"	73° 08' 20"
NON 22*	Woodbury	41 36 30	73 11 11
NON 23	Woodbury	41 36 24	73 11 46
NON 24*	Woodbury	41 36 14	73 12 43
NON 25	Woodbury	41 36 47	73 12 27
NON 26*	Waterbury	41 36 47	73 06 46

Appendix 2. Rb-Sr isotopic data. Isotopic ratio are given as atomic ratios and isotope concentrations are given as parts per million.

SAMPLE	$^{87}Sr/^{86}Sr$	^{86}Sr	^{87}Rb	$^{87}Rb/^{86}Sr$
Candlewood Lake- Northern Part				
NM 11	0.7248	18.35	47.39	2.55
NM 12	0.7292	16.13	55.34	3.39
NM 13	0.7275	16.85	54.76	3.21
NM 14	0.7334	15.09	60.75	3.98
NM 15	0.7224	20.18	47.46	2.33
NM 16	0.7312	15.91	58.74	3.65
NM 17	0.7225	21.84	51.20	2.32
NM 18	0.7533	9.90	74.31	7.42
NM 19	0.7533	8.86	64.24	7.17
NM 20	0.7179	26.18	44.32	1.67
Candlewood Lake- Central Part				
NM 1	0.7252	5.94	14.38	2.40
NM 2	0.7308	7.05	23.25	3.26
NM 3	0.7349	13.89	55.60	3.96
NM 4	0.7310	16.12	55.60	3.41
NM 5	0.7360	13.36	56.83	4.21
NM 6	0.7353	13.53	55.58	4.06
NM 7	0.7363	13.61	56.90	4.13
NM 8	0.7307	15.60	54.10	3.43
NM 9	0.7302	16.53	54.56	3.26
NM 10	0.7313	16.56	57.50	3.43

Appendix 2. continued

Candlewood Lake- Southern Part

RA 4	0.7218	18.43	35.40	1.90
RA 5	0.7328	13.54	52.88	3.86
RA 6	0.7338	13.03	52.93	4.02
RA 7	0.7259	14.04	40.00	2.82
RA 8	0.7325	12.44	43.12	3.43

Brookfield Center

RA 1	0.7488	11.02	68.51	6.15
RA 3	0.8802	2.44	67.61	27.37
RA 12	0.7886	3.91	48.96	12.37
RA 13	1.0047	1.41	65.91	46.25
RA 14	0.8336	2.50	49.93	19.71
RA 15	0.8589	2.21	52.54	23.50
RA 16	0.9748	1.79	77.71	82.94

Nonewaug Pluton (* indicates samples used for isochron age; see App. 3)

NON 11	0.7295	14.81	30.87	2.06
NON 12*	0.7324	13.77	42.12	3.02
NON 13*	0.7514	7.90	51.27	6.41
NON 14*	0.7264	19.03	35.87	1.86
NON 15*	0.7271	18.68	36.70	1.94
NON 16*	0.7420	8.33	39.01	4.63
NON 17*	0.7395	13.02	54.47	4.14
NON 18*	0.7256	17.75	29.21	1.63
NON 19	0.7329	14.41	52.75	3.62
NON 21	0.7336	19.50	35.14	1.78
NON 22*	0.7563	7.10	52.47	7.31
NON 23	0.7518	7.20	50.46	6.93
NON 24*	0.7582	6.78	53.06	7.73
NON 25	0.7372	16.63	47.48	2.82
NON 26*	0.7341	15.00	51.93	3.42

Appendix 3. Textural comments on the Nonewaug-type granite. Samples identified with a (*) were used to calculate the isochron age of the pluton.

SAMPLE	COMMENT
NON 11	Plumose muscovite in area
NON 12*	Medium-grained granite
NON 13*	Medium-grained granite
NON 14*	Medium-grained granite
NON 15*	Medium grained granite
NON 16*	Medium-grained granite
NON 17*	Medium-grained granite
NON 18*	Medium-grained granite
NON 19	Plumose muscovite in area
NON 21	Metasedimentary selvages of biotite in sample
NON 22*	Medium-grained granite
NON 23	Pegmatitic sample
NON 24*	Fine to medium-grained granite
NON 25	Pegmatitic sample
NON 26*	Medium to coarse-grained granite