GEOLOGY IN THE VICINITY OF THE HODGES COMPLEX AND THE TYLER LAKE GRANITE, WEST TORRINGTON, CONNECTICUT

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INTRODUCTION AND TRIP PURPOSE

Modern stratigraphic and structural studies of lower Paleozoic metamorphic rocks in the New England Appalachians have defined distinctions between miogeoclinal, transitional, and eugeoclinal tectonostratigraphic units (Hatch and others 1968, Cady 1969, Hall 1976, 1980, and Robinson and Hall 1980). Many workers in western Connecticut have noted the abundance of Proterozoic Y gneiss and autochthonous lower Paleozoic migeoclinal cover rocks to the west of Cameron's Line and the abrupt eugeoclinal character of the Hartland Formation to the east (Agar 1927, Cameron 1951, Rodgers and others 1959, Hatch and Stanley 1973, and Merguerian 1983).

Recent interpretations suggest that Cameron's Line is an important deep-seated ductile fault in the medial Ordovician Taconic suture zone separating transitional rocks (Waramaug Formation) from essentially coeval eugeoclinal rocks (Hartland Formation).

Intruded along Cameron's Line in West Torrington, Connecticut, the Hodges mafic-ultramafic complex and the Tyler Lake granite are the products of medial Ordovician plutonism. In collisional orogens, the mechanisms of deep-seated suturing and plutonism remain enigmatic. This trip examines the structures developed at Cameron's Line, the geologic relations of the Hodges Complex and the Tyler Lake granite, and the metamorphic stratigraphy and structure of the lower Paleozoic Waramaug and Hartland wall rocks.

REGIONAL SETTING

The crystalline terrane of western Connecticut consists of a diverse assemblage of Proterozoic to lower Paleozoic metasedimentary and metaigneous rocks which can be traced from New York City northward into the Connecticut Valley-Gaspe synclinorium (Fig. 1). Separated by Cameron's Line, a major ductile shear zone in the New England Appalachians, two major tectonostratigraphic terranes compose the geologic framework of western Connecticut (Fig. 2).

Cameron's Line delimits the easternmost exposures of Proterozoic Y gneiss and overlying lower Paleozoic miogeoclinal rocks (Rodgers and others 1959, Hall 1980, Merguerian 1983). Together they represent deformed North American craton and overlying shelf deposits. Included in the western terrane are metamorphosed Cambrian to Ordovician allochthonous rocks such as the Waramaug Formation and the Hoosac Schist, deposited transitionally between shallow and deep water realms (discussion below).

The Hartland Formation comprises the eastern terrane and occurs to the east of Cameron's Line. The Hartland is a metamorphosed sequence of eugeoclinal rocks formerly deposited on oceanic crust. Judging by metamorphic minerals the western and eastern terranes were juxtaposed at depths of $\simeq$20 km along Cameron's Line during lower Paleozoic times.

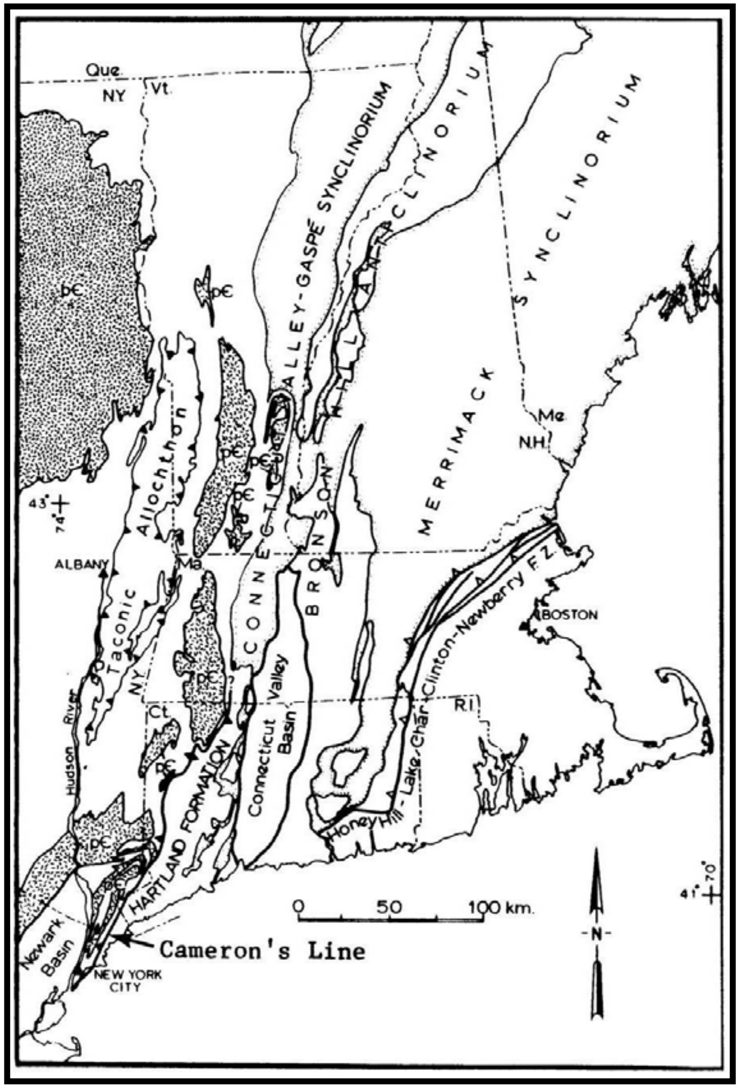

Figure 1 - Regional index map of New England. (after Williams 1978.)

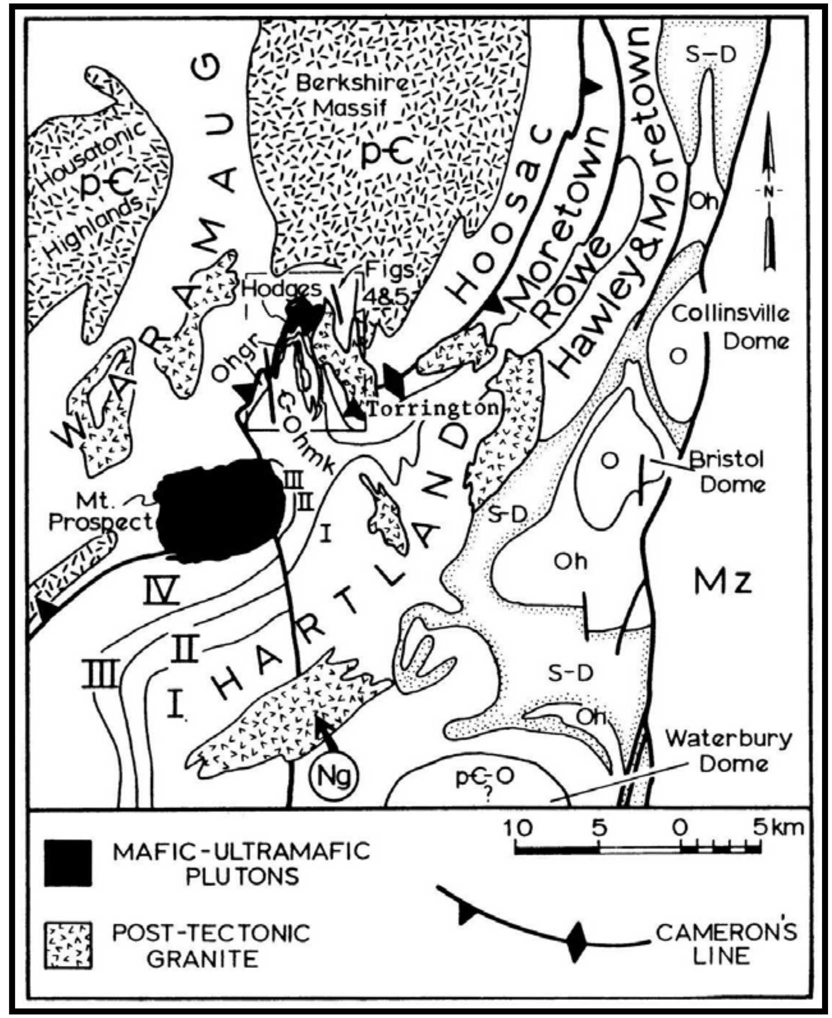

Figure 2 - Geological sketchmap showing the lithostratigraphic correlations between rocks of the West Torrington area and adjacent regions. Oh=Hawley Fm., Om Moretown Fm., Ng=Nonewaug granite. After Hatch and Stanley (1973), Gates (1967), Merguerian (1983), and Rodgers and others (1959).

The force behind such deep-seated deformation presumably resulted from a collision between a volcanic arc terrane and the passive margin of North America. Presently the arc terrane is exposed in the Bronson Hill Anticlinorium and its extension southward into central Connecticut (Fig. 1). Note the northwest to southeast stratigraphic variation from miogeo-clinal to eugeosynclinal rocks from eastern New York State to central Connecticut (Fig. 3).

A number of lower Paleozoic calc-alkaline plutons occur both in the western and eastern terranes in southern New England. Near West Torrington the Hodges mafic-ultramafic complex and then the Tyler Lake granite were sequentially intruded across Cameron's Line (Merguerian 1977). They are interpreted as late syn-orogenic plutons due to their formerly elongate shapes and since the regional metamorphic fabrics related to the development of Cameron's Line in both the bounding Waramaug and Hartland Formations are contact metamorphosed. The recognition of significant medial Ordovician plutonism across Cameron's Line (Mose 1982, Mose and Nagel 1982, Merguerian and others 1984, Amenta and Mose 1985) establishes a Taconian or possibly older age for the formation of Cameron's Line and the syntectonic development of regional metamorphic fabrics in western Connecticut.

STRATIGRAPHY

The Waramaug Formation of Gates (1952) forms a belt up to 10 km wide from Torrington southward to New Milford, Connecticut (Fig. 2) where Clarke (1958) correlated the Waramaug and Manhattan Formations. Mapping by Jackson (1980), and Jackson and Hall (1982) near Kent, Connecticut, by Alavi (1975) near Bedford, New York, by Hall (1968a,b) in White Plains, New York, and by Merguerian and Baskerville (1986) in New York City support this correlation.

Regional correlations are shown in Fig. 3. The Waramaug has been redefined in northwestern Connecticut by Dana (1977) and Hall (pers. comm., 1981) where it is not as extensive as originally defined (Gates 1952). The Waramaug Formation is correlative and physically continuous between Connecticut and Massachusetts with the Late Proterozoic (?) to Cambrian Hoosac Schist (Hall 1971, 1976, Hatch and Stanley 1973, Merguerian 1977).

In the vicinity of West Torrington, the Waramaug (p€-Owg) crops out west, north, and northeast of the Hodges Complex (Fig. 4) and consist of a heterogeneous assemblage of rusty-, gray-, and locally maroon-weathering gneiss, mica schist, and granofels with subordinate amphibolite gneiss, amphibolite, and calc-silicate rocks (Stops 4, lunch stop and 5). Outcrops are massive and indistinctly layered with a nubby weathered surface due to resistant quartz+aluminosilicate segregations.

The Hartland Formation (Cameron 1951, Gates 1951, 1952) consists dominantly of aluminous metasedimentary and interlayered metavolcanic rocks. They are bound to the west by Cameron's Line and to the east, near the Collinsville, Bristol, and Waterbury domes (Fig. 2), are overlain by metamorphosed rocks of probable Silurian to Devonian age (Hatch and Stanley 1973). Rocks mapped as Hartland extend from New York City (Seyfert and Leveson 1969, Baskerville 1982, Merguerian and Baskerville 1986) through southeastern New York (Hall 1968a, Pelligrini 1977) and western Connecticut, northward to the Massachusetts state line (Hatch and Stanley 1973).

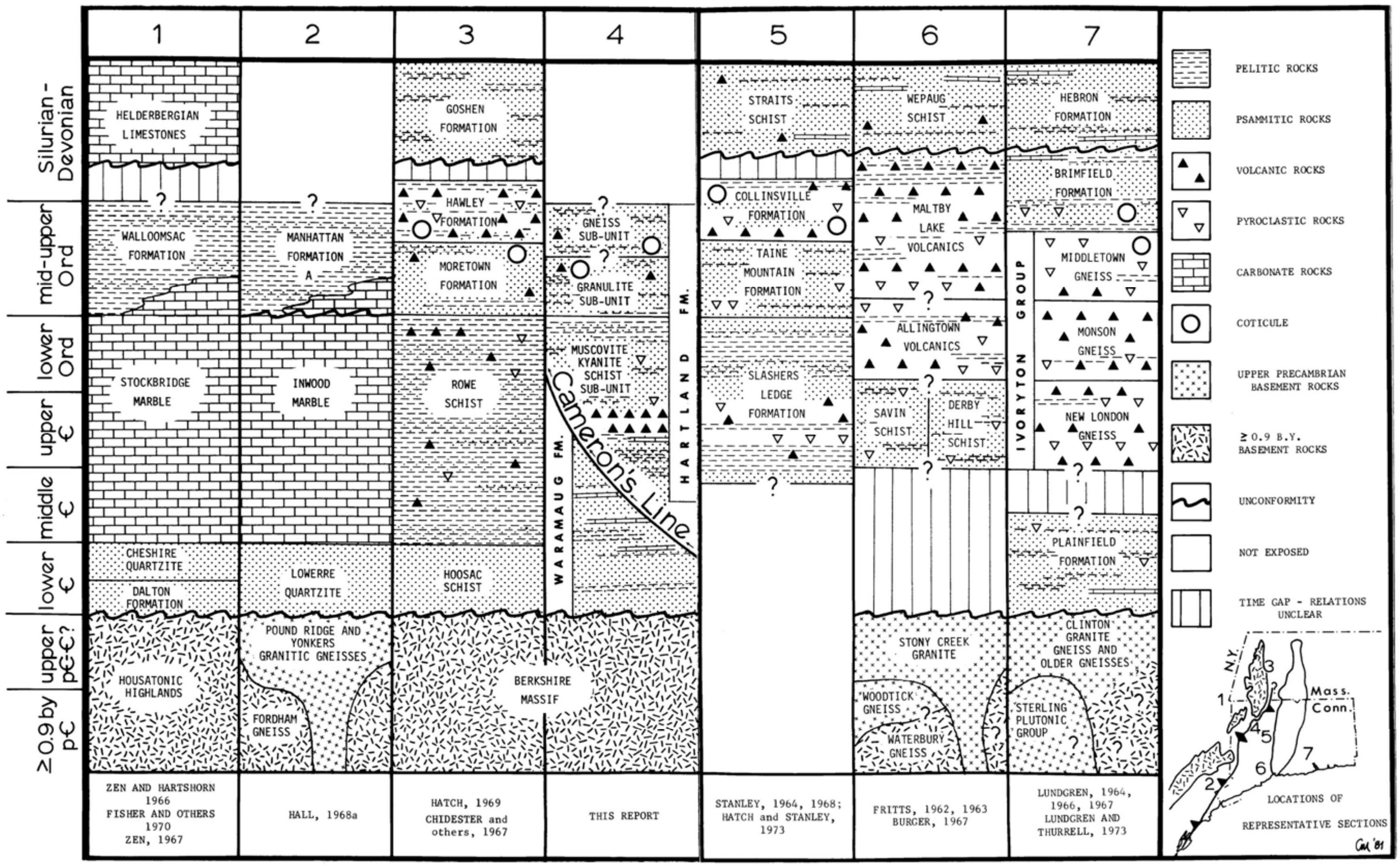

Figure 3 - Stratigraphic correlation chart for southern New England showing the interpreted protoliths of the lithologies depicted. Mixed symbols indicate relative, non-quantitative abundances of various pre-metamorphic lithologies.

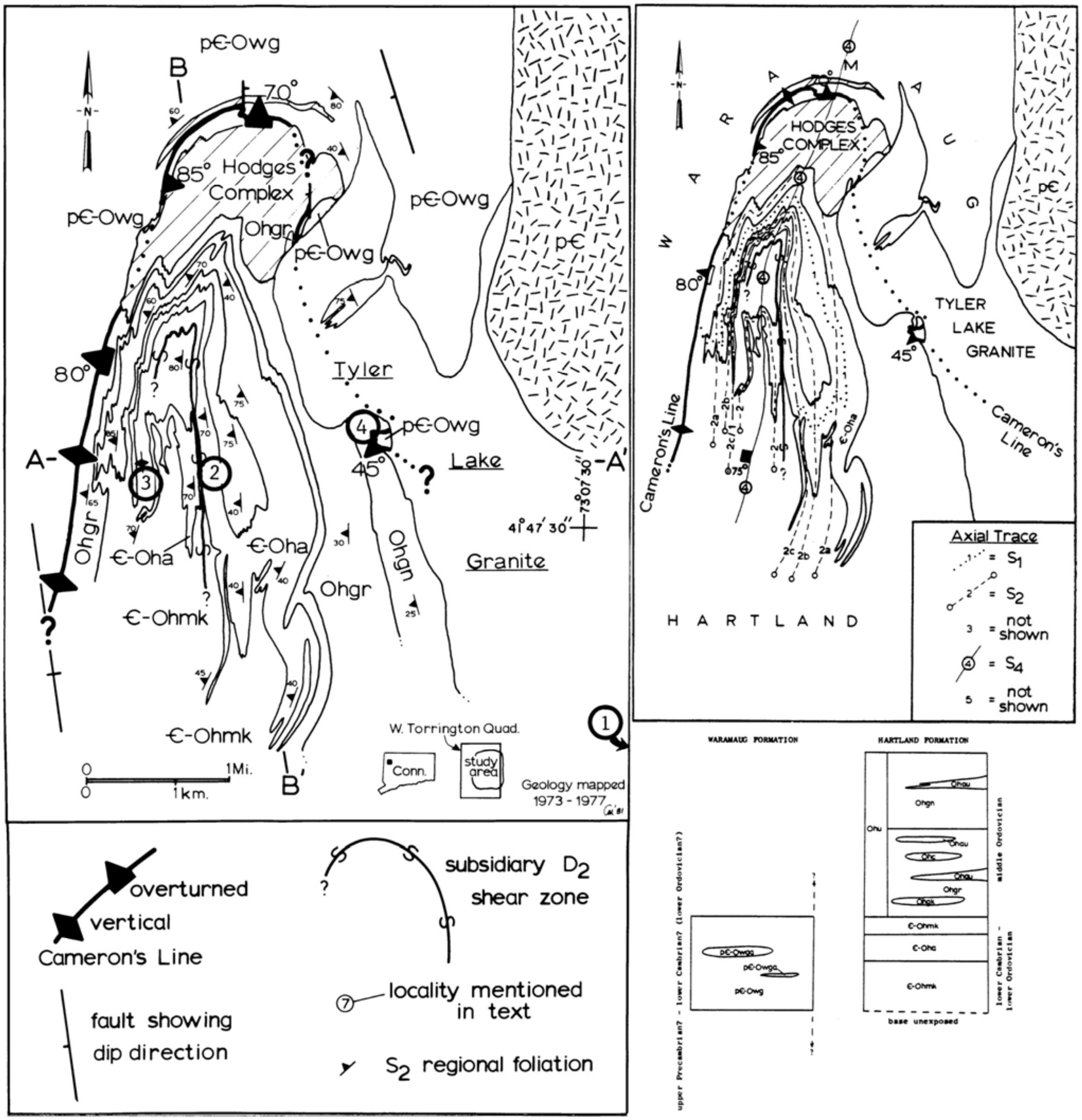

Figure 4 - Simplified geological map (showing Stops 2-4), axial surface map and stratigraphic column of a part of the West Torrington quadrangle (after Merguerian 1977, 1983).

In western Connecticut the Hartland Formation consists of a thick sequence of interlayered muscovite schist, micaceous gneiss and granofels, amphibolite, and minor amounts of calc-silicate rock, serpentinite, and manganiferous garnet-quartz granofels (coticule). Hartland rocks are correlative with metamorphosed eugeoclinal Cambrian to Ordovician rocks found along strike in New England (Fig. 3). A pre-Silurian minimum depositional age for the sequence is indicated since the Hartland is overlain by Silurian and Devonian metamorphic rocks and the dominant regional foliation in the Hartland is truncated by the 383± 5 m.y. Nonewaug granite (Mose and Nagel 1982).

In the vicinity of Torrington, the Hartland is subdivided into upper and lower members based on stratigraphic position (Figs. 3, 4). The lower member (Є-Ohmk) consists of lustrous gray-weathering muscovitic schist typically containing large (up to 10 cm) porphyroblasts of garnet, biotite, staurolite, and kyanite (Stop 3). A texturally and mineralogically diverse assemblage of thick, laterally variable amphibolites (Є-Oha) are interlayered within the lower member (Stop 2). The lower member grades, with some lensing, into the upper member.

The upper member (Stops 1, 4) consists of lustrous pin-striped muscovitic gneiss (Ohgn), well-layered quartzofeldspathic granofels and schist (Ohgr), amphibolite (Ohau), and subordinate quartzite, coticule, and calc-silicate rocks (Ohc) and lenses of muscovite-kyanite schist (Ohmk) (Figs. 3, 4). The upper and lower members of the Hartland Formation are correlative with the Rowe-Moretown-Hawley eugeoclinal sequence of western Masschusetts (Fig. 3).

Significant tectonic intercalation at Cameron's Line and intense regional isoclinal folding under amphibolite-grade metamorphic conditions create uncertainties in distinguishing between the Waramaug and Hartland Formations near Cameron's Line. Elsewhere, their unique lithologic character makes identification simple. Waramaug rocks are generally rusty- to gray-weathering, coarse- to medium-grained, gneissic, and granular to foliated with quartz-biotite and plagioclase the dominant minerals. Muscovite is typically present but not as abundant as in the Hartland. The Waramaug contains thin layers of amphibolite and amphibolitic gneiss which are typically granular and gray-green to black in color and rare tremolite-quartz calc-silicate layers.

In contrast, the Hartland rocks are gray-weathering and well layered, fine- to coarse-grained, and typically schistose with interlayers of granofels, amphibolite, and rare coticule. The rocks are very rich in muscovite and quartz and, to a lesser extent, plagioclase and contain thin to thick layers of greenish amphibolite.

The absolute ages of the Waramaug and Hartland Formations are unknown but they are basically considered time-stratigraphic correlatives by most workers (Hall 1976). They represent dominantly transitional slope-rise (Waramaug) and adjacent oceanic (Hartland) sequences deposited in the lower Paleozoic near the North American shelf and were subsequently deformed into metamorphic rocks and juxtaposed at depth along Cameron's Line.

THE HODGES COMPLEX AND THE TYLER LAKE GRANITE

Metamorphosed mafic and ultramafic rocks of the Hodges Complex underlie a 2.5 km^2 area (Figs. 4, 5). The complex is a steep-walled, folded, mushroom-shaped pluton with a hornblende gabbro core and dioritic chilled margin. A stock-like central intrusion and many smaller separated masses of pyroxenite and hornblendite crosscut the main gabbro-diorite pluton as well as foliated amphibolites of the Hartland Formation stretching to the south. The pluton is in direct contact with both the Waramaug and Hartland Formations and is surrounded by a narrow contact aureole.

All rocks of the Hodges Complex have been metamorphosed with recrystallization and overprinting of original igneous textures. Relict olivine, enstatite, hypersthene, augite, and hornblende are corroded and replaced by tremolite, actinolite, anthophyllite, cummingtonite, hornblende, magnesian chlorite, calcite, talc, and serpentine minerals. Gabbros and diorites are relatively unaltered although recrystallization of plagioclase and replacement of hornblende by biotite and chlorite has occurred.

The Hodges is subdivided into three mappable mataigneous rock units - Pp-= pyroxenite, hornblendite, Hg = gabbro, and Di = diorite. The ultramafic rocks (Pp) are typically highly-altered, medium-grained to pegmatitic, dense and deeply iron-stained, silver-green to dark-green to black hornblende orthopyroxenite, biotite-tremolite-orthopyroxenite, orthopyroxene hornblendite, hornblendite, and biotite hornblendite (Stops 6, 7).

The main gabbroic mass of the Hodges Complex (Hg) is composed of medium- to very coarse-grained, dark gray-weathering, hornblende plagioclase-biotite ± quartz gabbro (Stop 6). Labradorite (An_{50-55}) is generally clouded with oscillatory zoning and is about equal to the hornblende content. The hornblende contains pyroxene ghosts defined by opaques suggesting that pyroxene was an important mineral phase prior to metamorphism.

The dioritic rocks (Di) are by far the most variable in texture and mineralogy (Stops 5-7). They are greenish to black and white, poor to well-foliated, fine- to medium-grained, banded hornblende-plagioclase-biotite±quartz diorites. Alternating layers of subhedral hornblende together with euhedral to subhedral laths of plagioclase together define an igneous flow layering. The diorites form the flow layered chilled margin of the main gabbroic mass of the Hodges. The Tyler Lake granite (Stop 8) is an elongate pluton initially described by Gates and Christensen (1965) as the eastern mass of the Tyler Lake granite. It intrudes across Cameron's Line and includes xenoliths of the Hodges rocks at their contact zone.

The $S_1 + S_2$ regional foliation exerted a strong control on the original geometric form of the Hodges and Tyler Lake intrusives generating sheetlike, rather than equidimensional forms. As discussed later, minerals of the Hodges contact aureole postdate the S_2 regional foliation in the Waramaug and Hartland wallrocks. Post-intrusive folding has deformed Cameron's Line and the plutons, causing abundant metamorphic alteration of original igneous textures (Table 1).

STRUCTURAL GEOLOGY, INTRUSIVE RELATIONSHIPS, AND METAMORPHISM

The wall rocks of the Hodges Complex and the Tyler Lake granite have experienced a complicated Phanerozoic structural history that began with two phases of isoclinal folding (F_1 and F_2) yielding two sub-parallel regional foliations (S_1 and S_2). F_1 folds are rare and usually developed in amphibolites which were less ductile than the surrounding schistose rocks during subsequent deformation (Fig. 6a). However, an S_1 foliation and parallel compositional layering is commonly deformed by F_2 folds in both the Waramaug and Hartland Formations. The D_1 and D_2 events are similar in orientation, style, and metamorphism (amphibolite grade) and are considered progressive. They mark the initial prograde metamorphic pulse (M_1 in Table 1) that culminated during the formation of Cameron's Line.

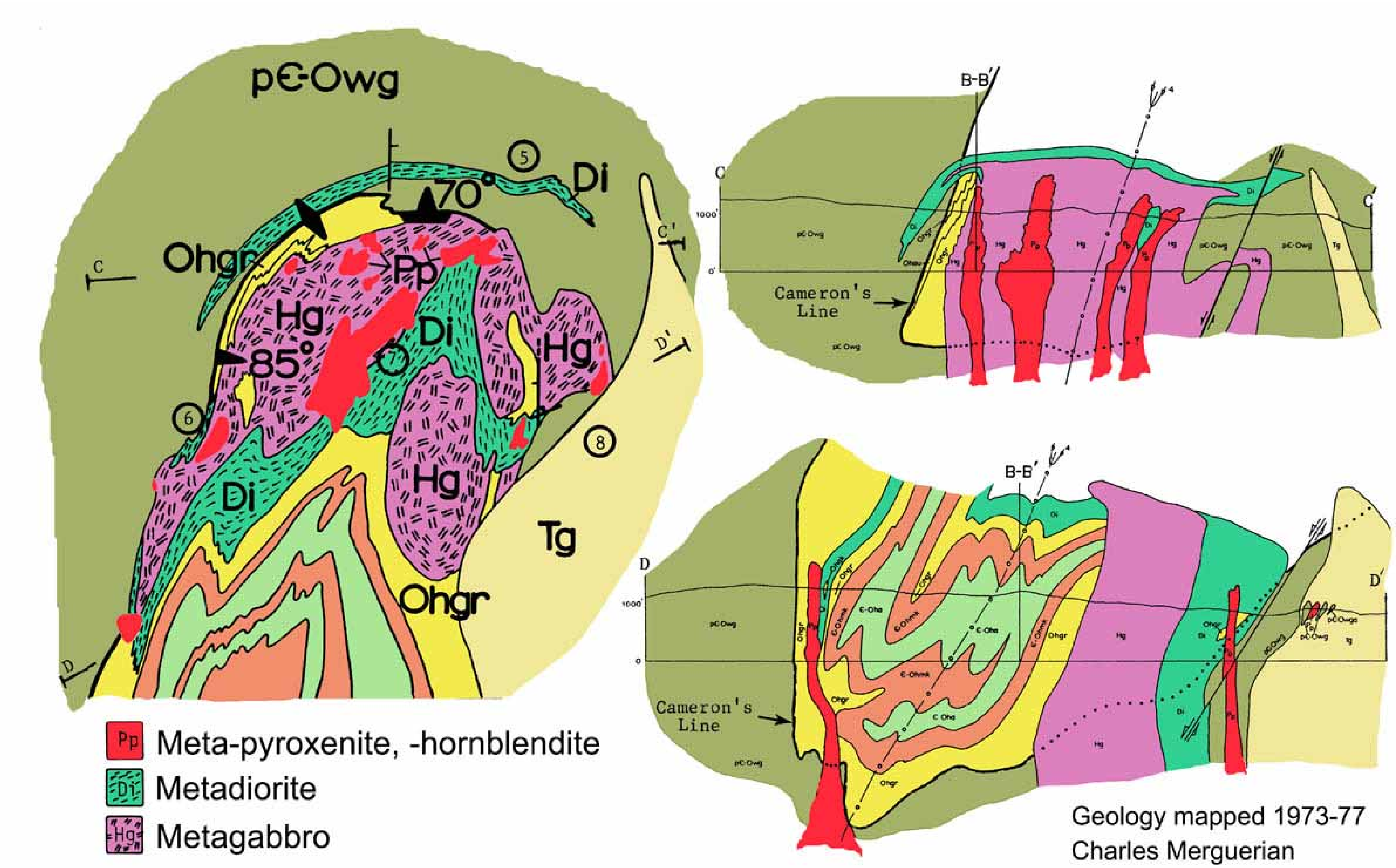

Figure 5 - Geologic map and sections of the Hodges Complex showing Stops 5-8.

Cameron's Line is a 15-90 m wide zone of intense localized isoclinal F_2 folds with limbs sheared parallel to S_2, transposition of S_1 fabrics, and regional truncation of Hartland subunits. The syn-metamorphic shear zone includes layers of mylonitic amphibolite intercalated with both Waramaug and Hartland rocks and, locally, deformed slivers of serpentinite (Stop 4). Away from Cameron's Line, D_2 resulted in the development of a penetrative regional foliation (S_2) in the bounding Waramaug and Hartland Formations. While it is unclear whether motion along Cameron's Line initiated during D_1, the regional parallelism of S_2 axial surfaces and the trace of Cameron's Line in West Torrington (Fig. 4) strongly suggest that the development of Cameron's Line and S_2 in the wall rocks are essentially coeval. A subsidiary D_2 shear zone, marked by mylonitic amphibolite (Stop 2) and a soapstone-talc body (optional Stop 2a) are also developed within the Hartland.

A secondary regional metamorphic pulse (M_2 in Table 1) occurred after the juxtaposition of the Waramaug and Hartland Formations since porphyroblasts of garnet, staurolite, and kyanite overgrow the S_2 foliation. The M_2 metamorphic pulse was reached after D_2 but before D_4 since M_2 porphyroblasts are deformed by S_4 cleavage. The contact aureole of the Hodges Complex also overprints the S_2 foliation and it is likely that the intrusion of the Hodges was synchronous with the regional M_2 event as shown in Table 1. Both the M_1 metamorphic pulse and the development of the Hodges contact aureole are pre-medial Ordovician events based on a 466±12 Ma Rb/Sr age on the Tyler Lake granite reported by Merguerian and others (1984). It is possible that the M_2 event is also of Ordovician vintage despite the fact that most workers in Western Connecticut attribute the growth of large post-regional foliation porphyroblasts to Acadian (middle Devonian) Barrovian metamorphism documented in Massachusetts (Hatch 1975, Stanley 1975, Robinson and Hall, 1980).

Open to tight, crenulate F_3 folds occur dominantly in the vicinity of the plutons (Fig. 6b). Often their axial surface cleavages are parallel to the margins of the plutons and they have little regional effect on the map pattern. They are interpreted as syn-intrusive folds; their axial surfaces are not shown in figure 4.

Near West Torrington the $S_1 + S_2$ foliations, Cameron's Line, and the Hodges and Tyler Lake plutons were strongly deformed by dextral F_4 folds (Fig. 6c) and cut by an associated axial planar spaced schistosity. S_4 is characterized by the growth of idioblastic biotite and hornblende and recrystallized quartz, by parting in M_2 garnet, staurolite, and kyanite porphyroblasts, and by brittle deformation of plagioclase twin lamellae. The S_4 schistosity crosscuts the large M_2 staurolitet kyanite±garnet porphyroblasts as well as the $S_1 + S_2 = M_1$ regional foliation (Table 1). Metamorphism (M_3) during the D_4 event fosters retrograde biotite and amphibole recrystallization. In addition, the D_4 event caused widespread metamorphic recrystallization, serpentinization, and chloritization in the Hodges Complex and recrystallization and domainal shearing in the Tyler Lake granite (Stops 5-8).

A fifth, and possibly sixth, deformation is suggested by the warping of the S_4 axial surface trace (Fig. 4) and by local open to crenulate folds with variable plunges and shallow NE and NW to W-trending axial surfaces. This deformation is low grade and is marked by recrystallized quartz and chlorite±white mica. These crosscutting structural, metamorphic, and intrusive relations are summarized in Table 1 and discussed in greater detail in Merguerian (1977, 1983). The D_x, F_x, S_x, and M_x nomenclature (to denote deformational event, fold generation, axial surface fabric, and metamorphic event, respectively) will be utilized in later field descriptions.

DEFORMATIONAL EVENT	LINEAR FEATURES	PLANAR FEATURES	IGNEOUS ACTIVITY	METAMORPHISM
D_1	F_1 isoclinal folds of compositional layering. L_1 quartz ribbing in gneisses and schists. Hornblende lineation in amphibolites.	S_1 gneissic layering in gneisses or hornblende-plagioclase foliation in amphibolites. Generally not recognized in schists.		? Amphibolite-grade M_1
D_2	F_2 penetrative isoclinal folds of early S_1 structures and compositional layering. L_2 mineral streaking in schists and gneisses.	S_2 regional foliation composed of oriented phyllosilicates$\pm$kyanite or sillimanite developed axial planar to F_2 folds.	? HODGES COMPLEX TYLER LAKE GRANITE *466±12 m.y.*	Amphibolite-grade M_2
D_3	F_3 shallow SW to NW plunging, open to tight, crenulate folds of the S_2 regional foliation. L_3 intersection lineation in massive rocks; crinkle axis in micaceous rocks.	S_3 crenulation or slip cleavage developed axial planar to F_3 folds. Oriented NW to WSW with shallow dips.	PEGMATITES	?
D_4	F_4 steep SW plunging dextral synformal folds of the S_2 regional foliation	S_4 crenulation cleavage, slip cleavage, or spaced schistosity developed axial planar to F_4 folds Orientation - N20°E, 75°NW.		Biotite-grade M_3 (retrograde)
D_5	F_5 open folds and warps with variable hingelines. L_5 intersection lineation.	S_5 slip cleavage and rock cleavage axial planar to F_5 folds oriented NW to W with variable dip.	?	continued retrograde

Table 1 - Linear and planar structural features and chronology of folding, igneous activity, and metamorphism in Torrington, Connecticut area.

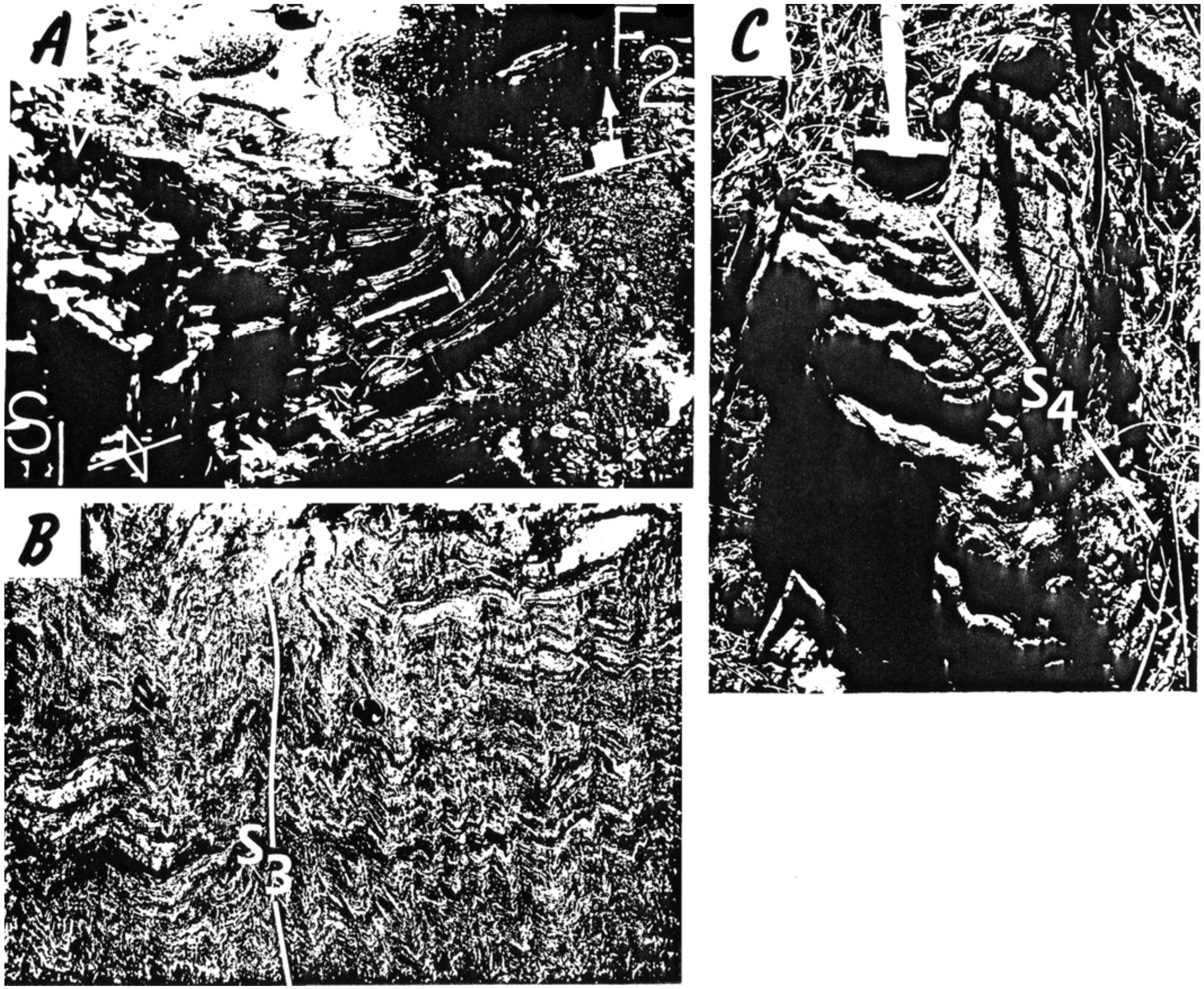

Figure 6 - a) Typical F_2 isoclinal fold of foliated (S_1) amphibolite away from Cameron's Line. S_1 can be traced into the axial surfaces of upright isoclinal F_1 folds. b) Typical F_3 folds in Hartland gneiss (Ohgn) near the contact with the Tyler Lake granite. c) F_4 fold in Hartland amphibolite Є-Oha showing axial planar slip cleavage (S_4). Hammer is 45 cm long.

STEREOGRAMS AND STRUCTURE SECTIONS

Stereograms of the major structural features described above are shown in figure 7. Stereogram 1 shows poles to S_2 in both the Waramaug and Hartland Formations.

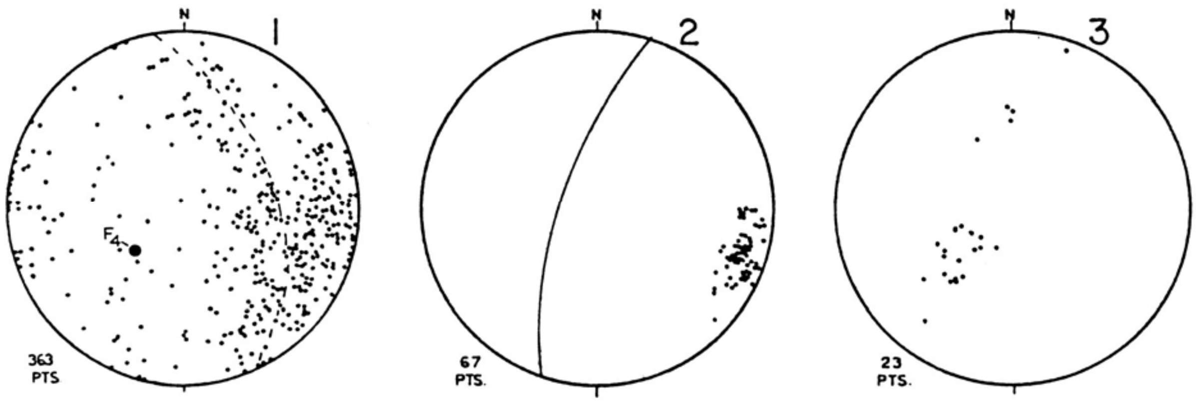

Figure 7 - Stereograms of structural elements.

The wide scatter of poles distributed about a NW-SE girdle indicates the presence of post-D_2 deformation. Poles to S_4 (Stereogram 2) and F_4 fold axes and L_4 intersection lineations (Stereogram 3) shows a consistent trend for $S_4 \approx$N19°E, 72°NW and $F_4 \approx$ S50°W @ 60°. Clearly, the girdle distribution of S_2 poles is largely the result of F_4 folding. Some scatter due to local F_3 and F_{5+} folds may have also occurred.

Sections in figure 8 are drawn from map data and axial surface traces shown figure 4 but the exact configuration of F_1 closures in the subsurface is hypothetical due to extensive D_2 transposition. The major obvious structure in section A-A' is a dextral F_4 synform with a steep western limb (vertical to locally overturned toward the east) and a shallow west-dipping eastern limb. The interference of F_1 and F_2 folds yields a complex interdigitating map pattern of Harland subunits. The section shows superposition of F_4 on the older structures, folding of Cameron's Line and the subsidiary D_2 shear zone, the truncation of Hartland subunit Ohgn against Cameron's Line, and the cross-cutting relationship of the Tyler Lake granite.

Section B-B' shows a north-south view roughly parallel to the trace of S_4. Again, the complicated fold geometry of the Hartland subunits, truncation of Hartland subunit Ohgn, and crosscutting relationship of the Hodges Complex is indicated.

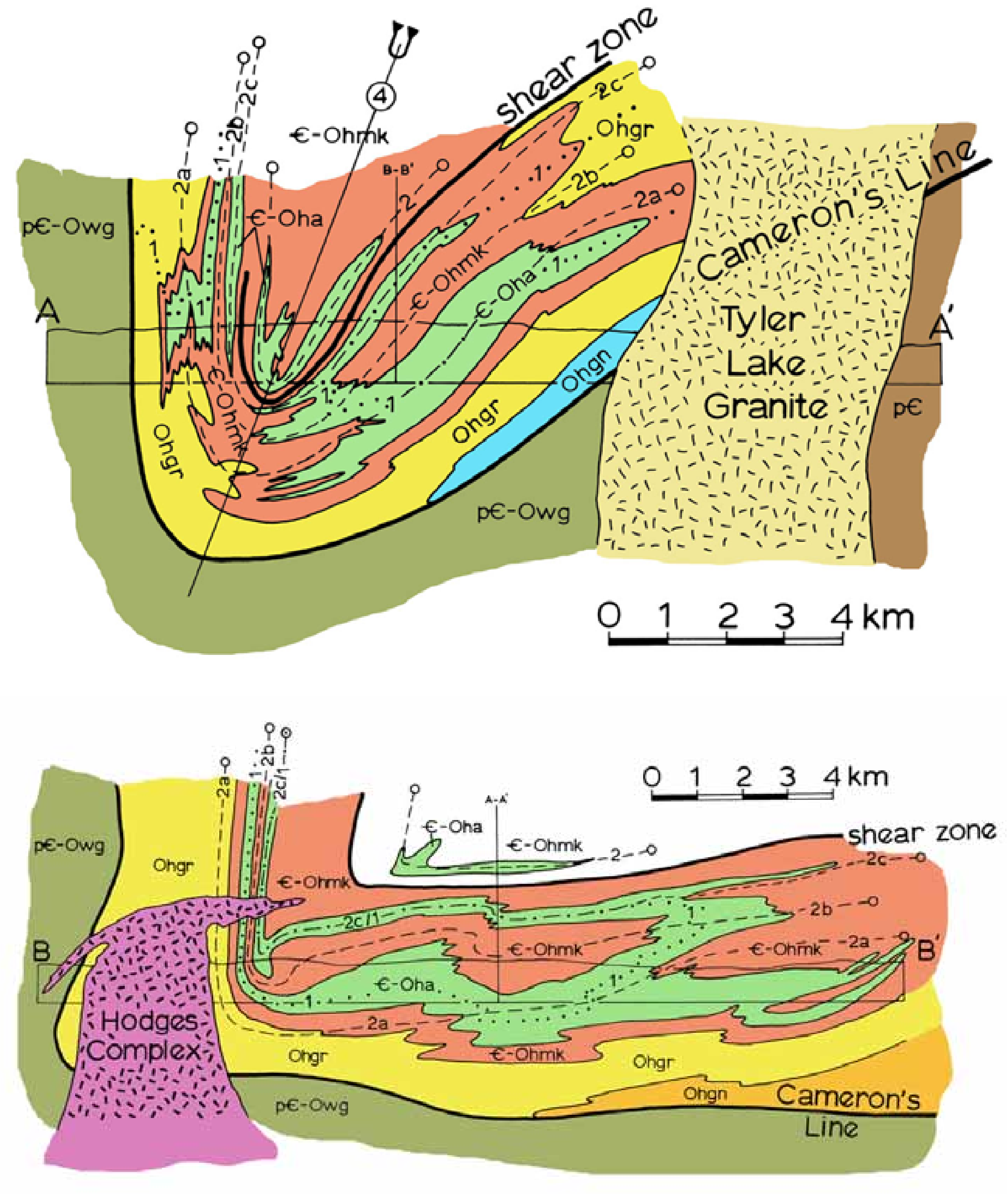

Figure 8 - Geologic structure sections. Section lines are shown in figure 4. No vertical exaggeration.

ACKNOWLEDGMENTS

The main phase of field work for this study was performed in 1973-1977 but subsequent study and remapping has continued to the present. Financial and technical support was provided by the Connecticut State Geological and Natural History Survey (Grants 81-506 and 82-506), Hofstra University, and Duke Geological Laboratory. I gratefully acknowledge assistance in the field by G.V. Bennett, L. Bean, and P. LaJuke and the help and support of Dr. Nicholas M. Ratcliffe, Ray Wadhams, and John A. Carter during the early stages of this study.

ROAD LOG

From New Haven, Connecticut, travel west on State Route 34 for roughly 6 miles to the intersection with State Route 8 near Derby. Take Route 8 northward through Waterbury and Thomaston for roughly 32 miles to exit 42 (Litchfield-Harwinton). Bear right (east) on Route 118 at the end of the exit ramp and park in the commuter parking lot. Plan to arrive at the assembly point (Stop 1) at 9:00 AM sharp. We will pause for lunch between stops 4 and 5 and there will be places to pick up food if necessary. All of the stops are within the West Torrington 7-1/2 minute quadrangle except for Stop 1 (Torrington quadrangle).

Stop 1 - Hartland Formation (upper member) granofels, schist, and amphibolite.

A convenient place to initiate today's fieldtrip, the outcrops forming the roadcut across from the commuter lot were originally described by Martin (1970). Here, 2-15 cm-scale very well-layered muscovite-biotite-plagioclase-quartz-(hornblende)-(garnet) granofels occurs with interlayered schist of similar mineralogy. The major minerals are listed in order of decreasing abundance; those in parentheses are not found in all exposures. The abundance of muscovite in the granofels and schist creates a lustrous sheen from foliation surfaces reflecting sunlight. A 2 m thick layer of hornblende-plagioclase-biotite-epidote-quartz-(garnet) amphibolite is exposed on the south-facing portion of the outcrop. The pervasive interlayering of granofels and schist, high muscovite and plagioclase content, and presence of amphibolite suggests that protoliths of these rocks were volcaniclastic graywackes and interlayered shale with subordinate basalt flows. The Hartland upper member is similar to and correlative with the Moretown Formation of western Massachusetts (Fig. 3).

The dominant layering is parallel to the composite $S_1 + S_2$ regional foliation, all striking roughly N65°E with dips of 60°NW. The $S_1 + S_2$ foliation is deformed by crenulate F_3 folds with axial surfaces oriented N30°E, 26°SE. The F_3 hingelines are expressed as L_3 crinkle-axis lineations in highly micaceous layers and as L_3 intersection lineations in more massive granofels. The F_3 and L_3 elements trend N55°E and plunge 9°. Note the upright warping of S_3 axial surface traces and the decrease in wavelength of F_3 folds in mica-rich interlayers. A 2 m thick pegmatite intrudes across the S_3 axial surfaces, locally rotating F_3 folds and older fabrics. Note the F_4 "z" folds with N20°E, 84°NW axial-planar slip cleavage.

Near the eastern end of the roadcut, L_2 lineations are deformed by subhorizonal F_3 folds and overprinted by L_3 lineations. The associated S_3 axial surfaces (N40°E, 20°SE) are warped by late F_4 crenulations with axial surfaces oriented ≈N25°E, 70°NW. Broad arching by later F_{5+} is also evident.

On the west-facing portion of the roadcut adjacent to the northbound entrance ramp for Route 8, F_2 intrafolial folds occur in thinly layered granofels. The S_2 axial surface strikes N55°E and dips 56°NW and F_2 hingelines are subhorizontal, trending N55°E-S55°W. The F_2 folds deform a pre-existing S_1 mica foliation. Many amphibolite layers are exposed to the north along the roadcut.

MILEAGE

Total	Interval	
0.0	0.0	Exit the commuter lot and take the northbound ramp for Route 8 toward Torrington. Note the upright F_2 folds in outcrops 0.6 miles from the starting point. At exit 44 (Routes 4 and 202 - Downtown Torrington) follow the exit ramp to the traffic signal.
3.3	3.3	Make a left travelling westward on Route 202 (East Main Street) past three traffic lights.
3.9	0.6	At the fourth traffic light bear right (across Main Street) up the hill onto Water Street. Follow Water Street past the railroad tracks to the traffic light.
4.3	0.4	Turn left onto Church Street. Drive over the Naugatuck River which separates Proterozoic Y gneiss of the Berkshire massif on the east from the Tyler Lake granite on the west. Follow Church Street to the small traffic triangle.
4.6	0.3	Turn left (west) driving uphill onto Highland Avenue. For the next 0.9 miles, the Tyler Lake granite crops out in wooded areas away from the road. Pass Allen Road on the right (5.2 mi.) and Stop 4 near Patterson Pond (5.6 mi.). Continue west, now driving on Ohgr and pass the radio towers to the right (6.3 mi.) which essentially mark the contact between the upper and lower members of the Hartland.
6.4	1.8	Pass Westside Road on the right and Rossi Road on the left and continue uphill to the massive outcrops on either side of the road (here known as Soapstone Hill Road!).
6.8	0.4	Park in the bend of the road just past the outcrops.

Stop 2 - Hartland Formation (lower member) amphibolite and subsidiary D_2 shear zone.

The roadside outcrops consist of fine- to medium-grained, dark-green hornblende-plagioclase-biotite-(quartz)-(epidote)-(chlorite)-(garnet) amphibolite with lineated prismatic hornblende. Elliptical quartz segregations up to 4 cm thick lie within the S_2 foliation. Elsewhere, 1-2 m thick felsic granofels ±hornblende, ±biotite, ±chlorite are interlayered with the amphibolite and muscovitic schist.

The S_2 foliation strikes N15°W and dips 67°SW with a prominent L_2 hornblende lineation trending N80°W and plunging 65°. S_1 is essentially coplanar with S_2 due to intense transposition and overprinting during D_2. S_2 and L_2 parallel the axial surfaces and hingelines, respectively, of rootless F_2 isoclinal folds exposed on gently northeast-dipping joint faces. The S_1 foliation, composed of hornblende and plagioclase, is locally preserved in F_2 hinges.

The amphibolite tends to break into wedge-shaped pieces due to the coplanar $S_1 + S_2$ foliation and an oblique S_4 spaced cleavage striking N-S and dipping 75°W. Oriented samples show S_4 defined by idioblastic biotite, the product of M_3 metamorphism.

Walk 110 m west on Soapstone Hill Road where amphibolite outcrops exhibit S_2 mylonitic layering (N14°W, 82°SW). Between these outcrops the muscovite schist is phyllonitic and thin (Figs. 4, 8). The mylonitic textures may mark a subsidiary D_2 shear zone which imbricates the Hartland amphibolite. Alternatively, shearing could simply be the result of ductility contrasts developed across the amphibolite-schist contact.

Stop 2a (Optional) - Soapstone Quarry

Walk north on a dirt trail immediately west of the parking area for Stop 2. Along the way, ridges are composed of amphibolite and the intervening valleys are underlain by muscovitic schist. Roughly 700 m north the trail ends at a 90 m long by 20 m wide pit of a former soapstone quarry. (They don't call it Soapstone Hill Road for nothing, you know!)

The excavation, which is oriented parallel to S_2 in the bounding muscovite-chlorite schist, produced commercial quantities of soapstone. Blocks from the tailings pile include talc-tremolite schist, chlorite schist, and very-coarse grained amphibolite rich in opaque minerals.

The quarry is on-strike with mylonitic amphibolite to the south. The elongate shape parallel to S_2 and foliated nature of the altered serpentinite body suggests that the soapstone-talc body represents ultramafic rock deformed during D_2 and possibly D_1. It may mark a syntectonic ultramafic intrusion (Gates and Christensen 1965) or a small sliver of ophiolite.

6.8	0.0	Continue west on Soapstone Hill Road and pull into a large clearing to the left.
7.3	0.5	Outcrops for Stop 3 are in the woods north of the road.

Stop 3 - Hartland Formation (lower member) muscovite-kyanite-staurolite schist.

The lower member Hartland schist crops out less than 50 m north of the road. The rocks are highly lustrous., gray-weathering, medium- to coarse-grained, quartz-muscovite -plagioclase-biotite-opaque-(garnet)-(chlorite)-(apatite) schists often containing 1-10 cm porphyroblasts of kyanite, staurolite, and garnet, and more rarely plagioclase and biotite.

Quartz and muscovite are roughly equal in proportion, together composing more than half the rock. Deeply-eroded outcrops have a knotted appearance due to differentially weathered porphyroblasts. Granular, clear- to smoky-gray quartz pods are conspicuous and occur flattened into S_2. The lower member becomes markedly hornblende, chlorite, and/or biotite-rich near amphibolite contacts.

The muscovite schist, amphibolite, and rare felsic granofels of the lower member are probably derived from metamorphosed pelitic sediments with interlayered basalt and rare volcaniclastic layers. The rocks are correlative with the Rove Schist of western Massachusetts (Fig. 3).

The large, non-oriented porphyroblasts of kyanite, staurolite, and garnet overgrow the S_2 foliation and represent the M_2 metamorphism in Table 1. Kyanite tends to occur mimetically within S_2. Staurolite tends to form spongy porphyroblasts, sometimes twinned, protruding randomly from the schist.

7.3 0.0 Backtrack east on Soapstone Hill Road.

9.0 1.7 Make a sharp right onto a partly hidden dirt road just past Patterson Pond. Pull up as far as possible.

<u>Stop 4 - Cameron's Line and dismembered ophiolite.</u>

The mylonitic amphibolite (Ohau) outcrop on the dirt road occurs within Cameron's Line, a 90 m zone consisting of highly-sheared, tectonically intercalated lithologies of the Hartland (upper member) and the Waramaug Formations (Fig. 9). In the amphibolite, an S_2 mylonitic foliation (N85°W, 70°NE) is parallel to the axial surfaces of F_2 folds with sheared out limbs plunging 40° into N75°W (Fig. 10a). An S_1 foliation composed of aligned hornblende occurs in the F_2 hinge areas. A specimen collected from this outcrop after blasting in 1973 shows an F_1 isocline refolded by F_2 with significant shearing and recrystallization parallel to S_2 (Fig. 10b). F_3 folds with subhorizontal axial surfaces warp S_2. The mylonitic amphibolite is interlayered with lustrous muscovitic gneiss (Ohgn).

The Hartland crops out to the north, west and south (Figs. 4, 9). Follow the dirt road south, stopping first to examine the Hartland gneiss outcrops on the subdued knob to the east. Here, S_2 dips shallowly toward the west due to F_3 folding. About 120 m to the south, note mylonitic amphibolite in the woods to the east. S_2 strikes N40°E and dips 37°NW; L_2 trends S80°W and plunges 27°. The Tyler Lake granite crops out farther south and east (Fig. 9).

Walk back to Highland Avenue and walk east roughly 100 m. The first outcrop to the right (before the creek) consists of massive, rusty-weathering quartz-plagioclase-biotite-sillimanite-muscovite-garnet-chlorite-tourmaline gneiss of the Waramaug Formation. The laminated S_2 mylonitic foliation strikes N65°W and dips 32°SW. The Waramaug crops out to the south and north, thus Cameron's Line occurs between these outcrops and the cars.

Walking north, adjacent to the small creek, note the overturned F_3 fold with pegmatite intruded along S_3. The small hill to the west is underlain by southwest-dipping Waramaug gneiss. Trace the creek to where a 10 m isoclinally folded serpentinite body separates Waramaug rocks to the southeast from Hartland rocks to the west and northwest. Folded by F_2 folds (Fig. 10c), the serpentinite is zoned and highly altered containing relict olivine and orthopyroxene. The zoning (compositional? or tectonic?) is due to relative enrichment of greenish, intergrown cummingtonite and tremolite in the upper part of the body compared to the dense, black serpentine- and anthophyllite-enriched lower part.

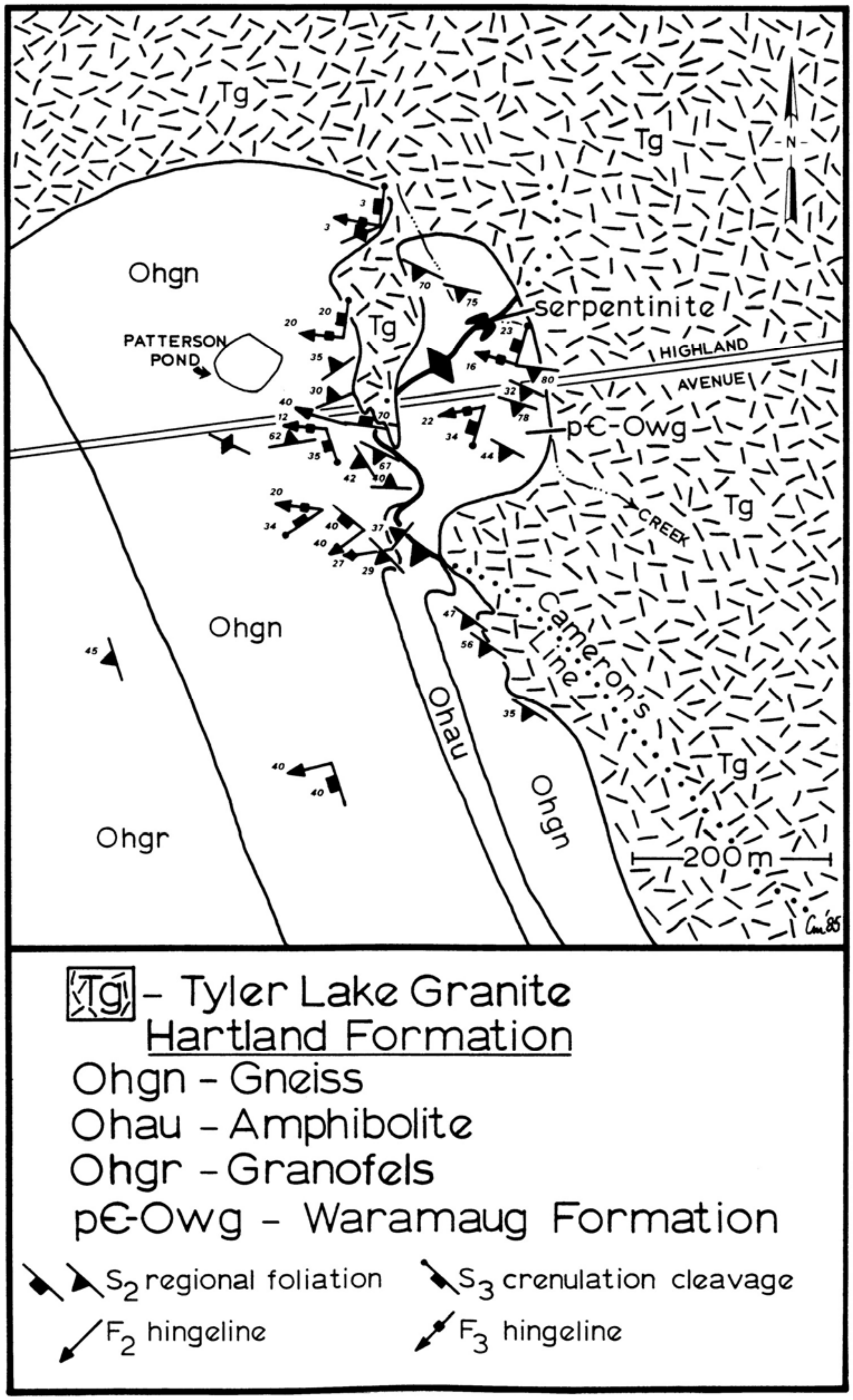

Figure 9 - Geological sketchmap in the vicinity of Stop 4.

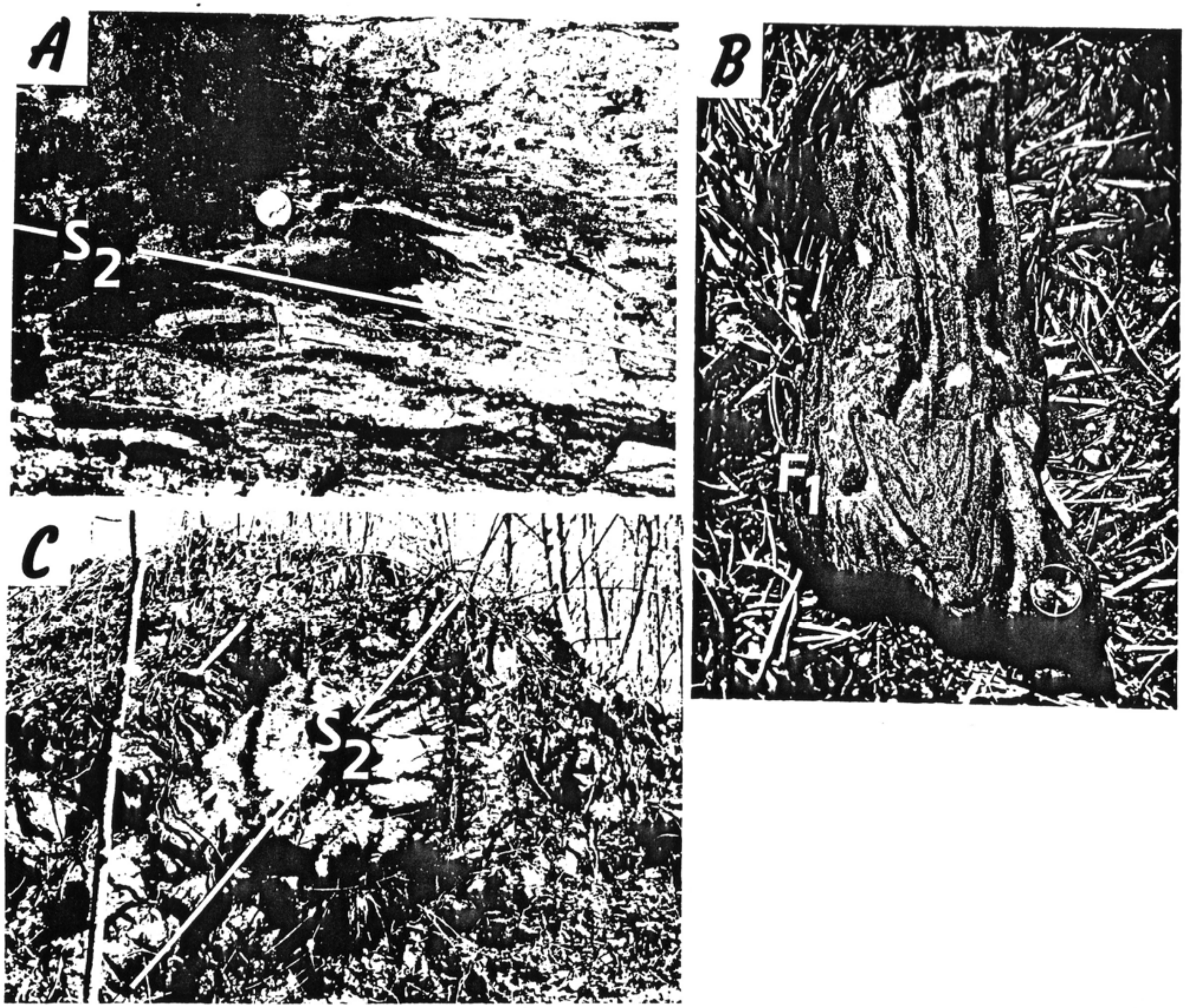

Figure 10 - a) F_2 folds in mylonitic amphibolite (Ohau) near Cameron's Line with limbs sheared parallel to S_2. b) F_1 isoclinal fold refolded by F_2 and sheared parallel to S_2. c) Isoclinally folded serpentinite occurring at Cameron's Line with a steep S_2 axial surface trace. The serpentinite is compositionally zoned and highly altered.

The body is distinct in mineralogy and texture from ultramafic rocks of the Hodges Complex. The overall eugeoclinal nature of the Hartland and the D_2 (and possibly D_1) deformation expressed in the serpentinite suggests that the body represents dismembered ophiolite (Merguerian 1979).

9.0	0.0	Drive east on Highland Avenue back to the turnoff from Church Street.
10.0	1.0	At the stop sign, turn left onto Riverside Avenue. Note the exposures of Waramaug amphibolite (pЄ-Owga) at the entrance to Charlene Susan Besse Park (10.9 mi.). Outcrops of Waramaug occur on the hilltop roughly 500 m due south. Continue north on Riverside Avenue to the intersection with State Route 4.
11.3	1.3	Turn right onto Route 4 and drive 0.25 miles east to Scarpelli's Drive-In. Those without lunch can pick something up here but we'll lunch at a nearby picturesque spot. With supplies in hand drive west on Route 4 to the traffic light.
11.8	0.5	Turn right onto Route 272 toward Wrightville.
12.6	0.8	Turn right onto Brass Mill Dam Road.
12.9	0.3	LUNCH STOP. Park in the wide area south of the dam. There are nice places to lunch to the northwest.

Lunchstop

Outcrops of the Waramaug occur in the woods to the west and excellent exposures occur in the spillway north of the cars. Here, the Waramaug and interlayered amphibolite are deformed into 15 m amplitude F_2 folds with N42°E, 57°NW axial surfaces and hingelines trending S40°W at 15°. F_5 crenulate "z" folds trend W at 37° with N15°W, 52°SW axial surface cleavage. Stillwater Pond may be fault controlled as abundant N20°W, 75°SW closely-spaced fractures cut the Waramaug exposures.

Road Log Resumes

12.9	0.0	Backtrack on Brass Mill Dam Road.
13.2	0.3	Drive across Route 272 uphill onto Hodges Hill Road.
13.7	0.5	At the stop sign, turn right onto University Drive (Town Farm Road).
14.1	0.4	Turn left onto John Brown Road and continue to dirt trail turnoff to the left.
14.3	0.2	Pull in as close as possible - we're at Stop 5!

Stop 5 - Waramaug Formation and contact relations of Hodges diorite sill

Walk roughly 60 m south on the dirt trail to an outcrop of massive but internally laminated, gray-weathering quartz-plagioclase-biotite-sillimanite-muscovite-garnet gneiss. Similar to the Waramaug at Stop 4, this outcrop exhibits a nubby-weathered surface due to differentially eroded quartz and sillimanite. A 30 cm layer of garnet amphibolite is isoclinally folded by F_2. Here, S_2 strikes N80°W and dips 83°SW with L_2 lineations trending N85°W at 26°. A spaced S_4 slip cleavage oriented N26°E, 84°NW deforms S_2.

The Waramaug crops out to the northeast and southwest (Fig. 11). Those to the northeast show S_1 metamorphic layering trending N20°E, 17°NW folded by upright antiformal F_2 "m" folds with axial surfaces oriented N75°W, 90° and hingelines trending N75°W at 17°. Outcrops to the southwest illustrate the typical massive, nubby-weathered appearance of the Waramaug Formation. S_2 strikes N80°W and dips 83°NE with a prominent L_2 lineation trending N70°W at 36°. L_2 is produced by intersection with S_1 which is locally preserved at a small angle to S_2. Commonly, S_1 is transposed into parallelism with S_2 but here S_1 dips 70°-75°NE due to F_2 isoclinal folding. The axial surface traces of F_2 isoclines are indicated in figure 11.

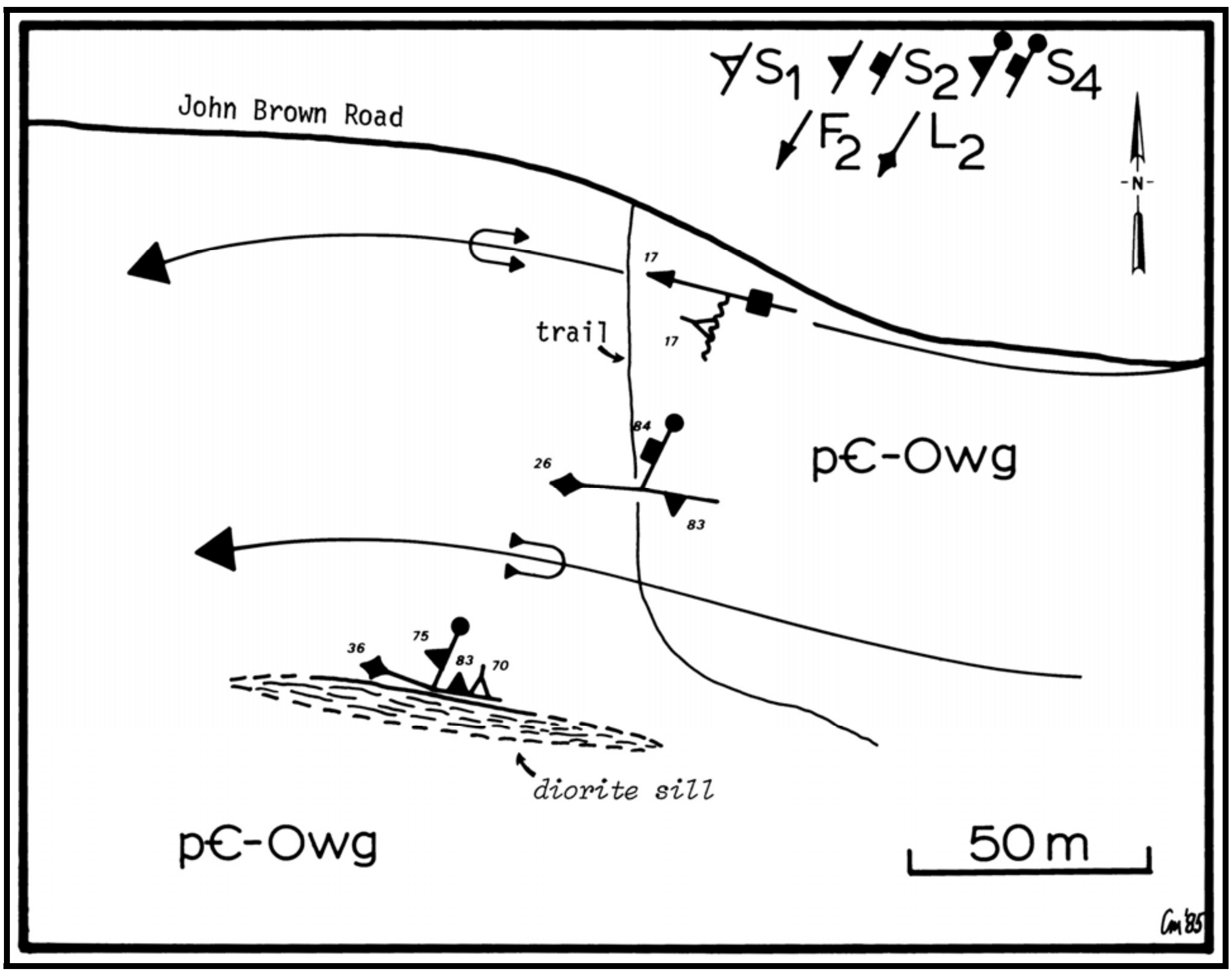

Figure 11 - Geological sketchmap of Stop 5 showing outcrops described in text and trace of major subvertical S_2 axial surfaces.

Note the abundance of garnet at the southern margin of the gneiss. The enrichment marks the contact effects of adjacent flow-layered diorite of the Hodges Complex. The diorite forms a small sill intruded parallel to S_2 in the Waramaug (Fig. 11). The microscope shows that the contact garnets (up to 1 cm) have grown across S_2 in the Waramaug wallrocks. Garnet enrichment also occurred in the diorite suggesting limited alumina metasomatism from the wallrocks took place.

In the woods to the east and west, Hodges diorites were intruded as sills and lit-par-lit injections (typically less than 10 m thick) along S_2 in the Waramaug. Flow-layering, defined by oriented hornblende and biotite set in a plagioclase matrix, is regionally parallel to S_2. In addition, garnetiferous diorite sills to the east are folded by SW plunging F_4 folds and cut by a spaced S_4 biotite schistosity (developed during M_3) oriented N25°E, 75°NW.

The near east-west trend of S_2 in this area is due to the effects of the major dextral F_4 fold in the area (Fig. 4). On the flanks of the F_4 fold (Stops 2-4) S_2 trends approximately NNE but in the F_4 hinge areas (Stops 1, 5) near east-west trends occur.

The post-S_2 field and textural evidence on the contact relations of the diorites fixes the time of intrusion to late-syn to post-D_2. D_4 crosscutting deformation and M_3 overprinting places an upper relative age limit on the Hodges intrusive episode.

14.3	0.0	Backtrack east on John Brown Road and turn right (south) on University Drive toward Route 4.
15.4	1.1	Turn right (west) on Route 4 and continue past Klug Hill Road and Wright Road to Weed Road.
16.4	1.0	Turn left (south) onto Weed Road and park about 0.1 miles south along the side of the road.
16.5	0.1	The 1320' hill to the west is Stop 6.

<u>Stop 6 (Optional) - Mafic and ultramafic rocks of the Hodges Complex</u>

Walking up the overgrown trail westward from Weed Road, the hill to the west is primarily composed of hornblende gabbro which is locally melanocratic with porphyritic textures. A west-dipping flow-layering is defined by mafic mineral concentrations and oriented hornblende. Coarse-grained pyroxenite and hornblendite crops out near the top of the hill and in a small pod to the south (Fig. 5).

Cameron's Line is here masked by intrusives but based on detailed tracing of screens and xenoliths, it traverses across the top of the hill in a S20°W direction. The Hodges rocks are in contact with both the Waramaug and Hartland to the west and east, respectively.

To the east, many xenoliths and screens of the Hartland (upper member) are contact metamorphosed with the development of cordierite, kyanite, sillimanite, staurolite, and garnet and the elimination of muscovite. Garnets up to 3 cm across overgrow the S_2 foliation in the Hartland amphibolite. Float draping the slopes to the east of Weed Road shows hornblende porphyroblasts overgrown on S_2 in Hartland amphibolite. Contact metamorphic assemblages are fully discussed at the next stop (7).

To the west near outcrops of the Waramaug, flow-layered diorite trends N25°E with vertical to steep easterly dips. The Waramaug is a dense hornfels peppered with garnet but the characteristic nubby weathering is still preserved. Along the western slope of the 1320' hill the Waramaug contains white tremolitic calc-silicate layers.

16.5 0.0 Return to Route 4 and turn right. Drive slow and prepare to make a left at Wright Road.

17.1 0.6 Follow Wright Road north and park near the first barn on the left.

17.2 0.1 The ridge to the northwest is Stop 7.

Stop 7 - Mafic and ultramafic rocks of the Hodges Complex

Walk from the barn northwestward onto a ridge where flow-layered diorites grade westward into gabbroic rocks. The diorites were multiply intruded as thin sill-like masses parallel to S_2 in the Harland Formation. Both the Hartland and the diorites are strongly enriched in garnet in the contact zone. Flow layering in the diorites is oriented N65°E, 70°NW. Massive gabbroic rocks occur near the top of the ridge and extend toward the northeast (Fig. 5).

To the west, beyond the ridge crest, a large NE-trending mass of pyroxenite and hornblendite crops out (Fig. 5). The ultramafic mass, which crosscuts the diorite-gabbro contact and truncates flow-layering in the diorite, is interpreted as the youngest intrusive in the Hodges Complex. Locally, the ultramafic rocks are strongly sheared and transformed into laminated serpentinite. The shear zone, oriented N36°E, 75°NW, cuts across the central part of the Hodges and is due to shearing along the axial surface of the major dextral F_4 fold which deformed Cameron's Line, the Hodges Complex, and the Tyler Lake granite into a broad dextral flexure. In fact, the plutons may have acted as immobile plugs localizing the F_4 hinge area. To the southwest, the S_4 shear zone is marked by zones of serpentinization and chloritization although domains of relatively unaltered pyroxenite and hornblendite are preserved.

Contact metamorphism of the Hodges wallrocks. The contact mineralization of the Hodges Complex overprints S_2 in both the Waramaug and Hartland Formations. In the contact aureole, typical foliated textures in the wallrocks are replaced by dense, finer-grained, garnet-rich, hornfels (Fig. 12a). Amphibolite in the contact aureole contains post S_2 garnet and hornblende as discussed at Stop 6 (Fig. 12b). Where gabbroic rocks intrude the Hartland Ohc subunit, a randomly oriented colorless amphibole of the cummingtonite-grunerite series forms. To the northeast of Klug Hill, gabbroic rocks intrude the Hartland granofels (Ohgr) producing a unique cordierite-kyanite-staurolite-garnet-biotite-plagioclase (An_{23}) assemblage (Fig. 12c). Abundant staurolite occurs in the contact aureole of Stop 6 and garnet there contains sillimanite microlites.

Table 2 shows the contact assemblages in the wall rocks of the Hodges Complex compared to regional assemblages outside the aureole. Randomly oriented contact phases, the assemblage cordierite-kyanite-staurolite-garnet and the absence of muscovite are characteristics of the Hodges aureole. These traits indicate that the Hodges was statically intruded between 5-8 kb (20-25 km) and 675°-700°C, near the $A1_2SiO_5$ triple point (Merguerian 1977).

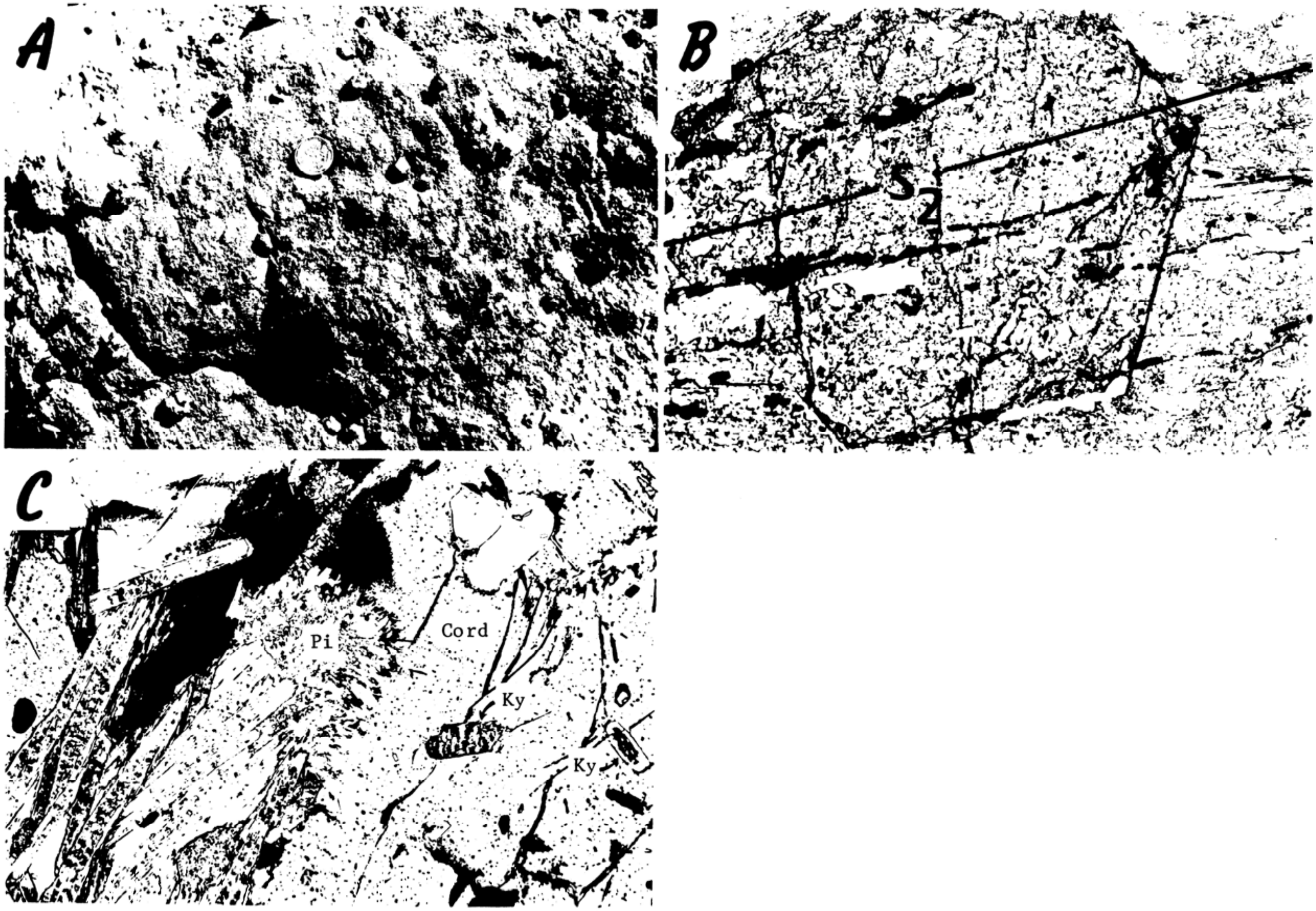

Figure 12 - a) Contact induced garnet enrichment in Hartland granofels xenolith from Stop 7. b) Garnet porphyroblast overprinting and including the penetrative S_2 foliation in Hartland amphibolite (Ohau) from contact aureole of the Hodges Complex at Stop 6. c) Cordierite (Cord) with typical pinnite (Pi) alteration coexisting with kyanite (Ky). Sample from contact of Hodges gabbro with Hartland granofels (Ohgr) on the northeast slope of Klug Hill.

SAMPLE	UNIT	CONTACT ASSEMBLAGE	REGIONAL ASSEMBLAGE AWAY FROM CONTACT	REMARKS
H-169	Ohgr	cord-ky-st-gt-bi-plag-qtz-chl	bi-musc-qtz-plag±ky	Contact with gabbro on Klug Hill. Sample was 5 feet from contact.
H-31	Ohgk	cord-ky-st-bi-qtz	musc-bi-qtz-plag-ky±st	
H-68	Ohc	st-gt-qtz-bi-sill	qtz-musc-plag	Contact of gabbroic and ultra mafic rocks with a screen of Hartland rocks.
H-69	Ohgk	cord-ky-gt-st-sill-bi-qtz-chl	musc-bi-qtz-plag-ky-±st	From the SW of the intersection of Weed Road and Route 4.
H-30b	Ohau	hyp-hb-plag-bi-op	hb-plag-bi-op	
H-43	PЄ-Owg	gt-plag-qtz-bi	gt-plag-qtz-bi	From contact of Waramaug and diorite NNW of the Hodges Complex.
H-52A	PЄ-Owg	ky-bi-qtz-plag-gt	musc-gt-ky-qtz-plag	
H-116	Ohc	grun-qtz	musc-bi-qtz-plag	From contact with diorite N of Route 4 and Klug Hill Road.
H-56	pЄ-Owga	hb-plag-bi-gt-op	hb-plag-bi-op	Direct from contact with diorite N of the Hodges Complex.
H-36	Ohau	hb-plag-bi-gt-op	hb-plag-bi-op	Direct from contact with ultra mafic rocks N of the Hodges Nickel Prospect.

KEY:

cord - cordierite	plag - plagioclase	hyp = hypersthene
ky - kyanite	qtz = quartz	hb = hornblende
st - staurolite	chl = chlorite	op = opaques
gt - garnet	sill = sillimanite	grun = grunerite
bi - biotite		

TABLE 2 - Contact assemblages in country rocks near the Hodges Complex compared with the regional assemblage outside the aureole.

There is no clear overprinting of contact minerals by M_2 kyanite, staurolite, or garnet porphyroblasts. Rather, identical minerals formed in the contact aureole suggesting that intrusion of the Hodges and regional M_2 metamorphism were coeval (Table 1). Local temperature increases adjacent to the Hodges Complex produced cordierite±sillimanite and fostered the breakdown of muscovite.

17.2	0.0	Drive back to Route 4 and turn left. Follow Route 4 east to Lovers Lane.
18.2	1.0	Turn right onto Lovers Lane and another immediate right into Ducci Electrical Contracting Co. parking lot.
18.3	0.1	The Tyler Lake granite crops out in the creek bed along the south edge of the lot.

End of log

Stop 8 - Tyler Lake granite

Tan-weathering, medium-grained, foliated quartz-microcline-plagioclase-muscovite-biotite-garnet-(chlorite)-(apatite) granite is exposed near the creek bed. An X-ray fluorescence analysis by Dr. D. Radcliffe of Hofstra University produced the following result: SiO_2 = 73.0, $A1_2O_3$ = 14.2, Fe_2O_3 = 1.4, MgO = 0.6, CaO = 0.8, K_2O = 5.5, Na_2O = 3.1, TiO_2 = 0.2, MnO = 0.1, loss on ignition = 0.7 (total = 99.6). The granite is foliated by cm-spaced micaceous layering (S_4) oriented N36°E, 60°NW. The S_4 foliation is cut by a faint slip cleavage (S_6?) oriented N10°E, 42°SW.

The Tyler Lake granite contains xenoliths of the Hodges rocks and is in direct contact with all major metamorphic units in the area (except Є-Ohmk and Є-Oha) suggesting a young intrusive age. Widely separated sample suites from the granite yield a well-defined 466±12 m.y. Rb-Sr isochron with initial Sr 87/86= 0.7082±0.0011 (Merguerian and others 1984). Since the Hodges was intruded following or nearly synchronous with D_2, this medial Ordovician age is proof of a Taconian or possibly older age for Cameron's Line. The Sr 87/86 data implies that the Tyler Lake granite was derived either from anatectic melting of the continental crust or materials derived from the crust (i.e.-Waramaug and Hartland sequences). Assimilation may have also been an important process during intrusion of the granite. The Hodges Complex may have been emplaced during the late stages of the Taconic orogeny when oversteepened subduction into a thick orogenic welt tapped mafic and ultra mafic magmas which ascended along Cameron's Line.

Thanks for coming on the trip - hope you enjoyed yourself!!

Route 4 (east) leads back to the center of Torrington and then to Route 8.

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