

**CONTACT METAMORPHISM AND INTRUSIVE RELATIONS
OF THE HODGES COMPLEX ALONG CAMERON'S LINE,
WEST TORRINGTON, CONNECTICUT**

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ABSTRACT

Restudy of the octopus-shaped Hodges Complex (Gates and Christensen, 1965) and surrounding rocks indicate that the Hodges is a small mass of pyroxenite, hornblendite, gabbro, and diorite intruded across the Waramaug-Hartland Formation contact (Cameron's Line) and that the tentacles are actually complexly refolded Hartland amphibolites.

Cameron's Line marks a zone of structural discordance characterized by intense localized folding (F_2), transposition of structures, truncation of Hartland sub-members, and shearing under metamorphic conditions, and is therefore interpreted as a fault. The pluton is not sheared or offset along Cameron's Line. In addition, a statically recrystallized contact aureole with cordierite-kyanite-staurolite- and garnet is overprinted on the fold-fault fabric (S_2), suggesting that intrusion postdated isoclinal folding, early metamorphism, and the development of Cameron's Line. Kyanite, staurolite, and garnet porphyroblasts grown during peak regional metamorphism throughout the study area, also postdate the fold-fault fabric (S_2).

A late southwest plunging overturned fold has refolded all older structures and the Hodges Complex into a broad dextral flexure. The peak of metamorphism (Acadian ?) may have been synchronous with the intrusion of the Hodges pluton at pressures below the Al_2SiO_5 triple point.

Because the Hodges Complex is intruded across and has induced a static contact metamorphism on the fault-related fabric of Cameron's Line, it is unlikely that this mafic-ultramafic mass is ophiolitic, despite its occurrence at what may be a major tectonic boundary.

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(at end)

- 1 - Regional geologic map showing the surface distribution of igneous rocks, major formations, and belts of rock aged Precambrian through Triassic. Explanation to Plate 1 appears at end.
- 2 - Geologic Map of the Hodges Complex and adjacent country rocks (1:12,000 scale with explanation).
- 3 - Axial Plane - Foliation Map.
- 4 - Geologic sections to accompany Plate 2 (on two sheets).

I - INTRODUCTION

The Hodges Complex (Gates and Christensen, 1965) is a metamorphosed Paleozoic igneous mass consisting of pyroxenite, hornblendite, hornblende gabbro, diorite, and serpentinite that is in contact with metasedimentary rocks of lower Paleozoic to Eocambrian (?) age. This complex, one of many straddling Cameron's Line in western Connecticut and southeastern New York, is situated within the West Torrington quadrangle, Connecticut (Figures 1, and 2, Plate 1).

Cameron's Line (Cameron, 1951) is thought to be a major discontinuity that stretches for over a hundred miles from The Bronx, New York City to southern Massachusetts. In many areas, such as western Connecticut, Cameron's Line separates an eastern eugeosynclinal metasedimentary sequence from schists, gneisses and carbonates with miogeosynclinal affinities in the west. A discussion of Cameron's Line will follow. Within the West Torrington quadrangle, Cameron's Line is drawn at the western boundary of the Hartland Formation at its contact with the Waramaug Formation.

Figure 3 is a simplified copy of Gates and Christensen's bedrock map showing the general structure and surface distribution of lithic types. They have interpreted the 4.5 mile long, octopus-shaped Hodges mass as a syntectonic intrusive, whose position was controlled by the axial portion of a prominent right-handed flexure of the country rocks. The southern tentacles of the Hodges Complex are interpreted as sill-like extensions of the main intrusive body that were emplaced in the Hartland Formation. The massive hornblende gabbro at the core of the Waramaug-Hartland Formation flexure to the north was envisioned as the feeder pipe.

Textural changes within the mass are obvious with "igneous looking" coarse-textured gabbroic rocks in the northern end and well-foliated schistose amphibolites in the tentacles to the south. Gates and Christensen believed that variation in texture was gradual, and that the pronounced metamorphic fabric in the sill-like bodies was the result of increased metamorphic crystallization in the thinner, more deformed parts of the pluton.

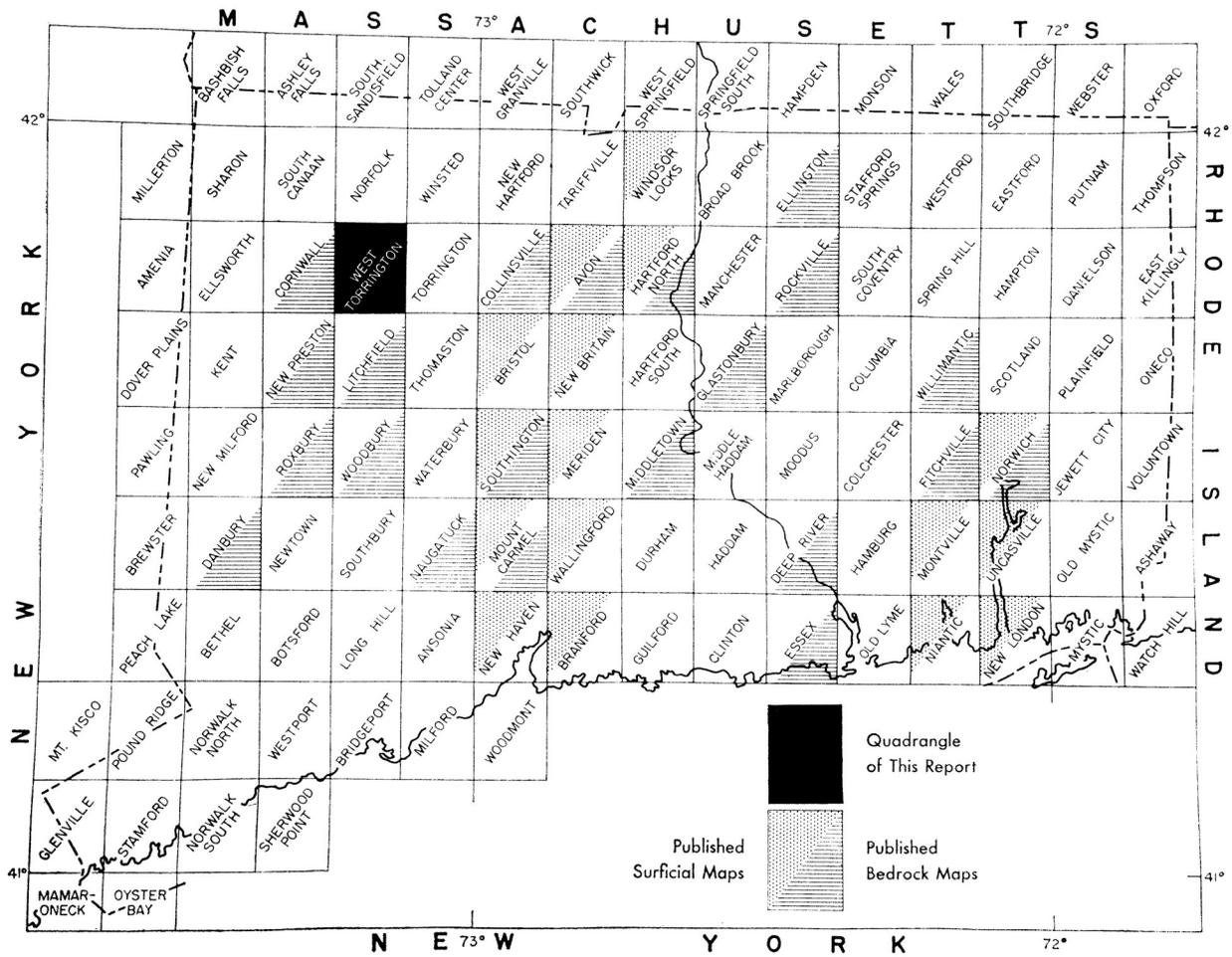


Figure 1 – Index map of quadrangles in Connecticut.

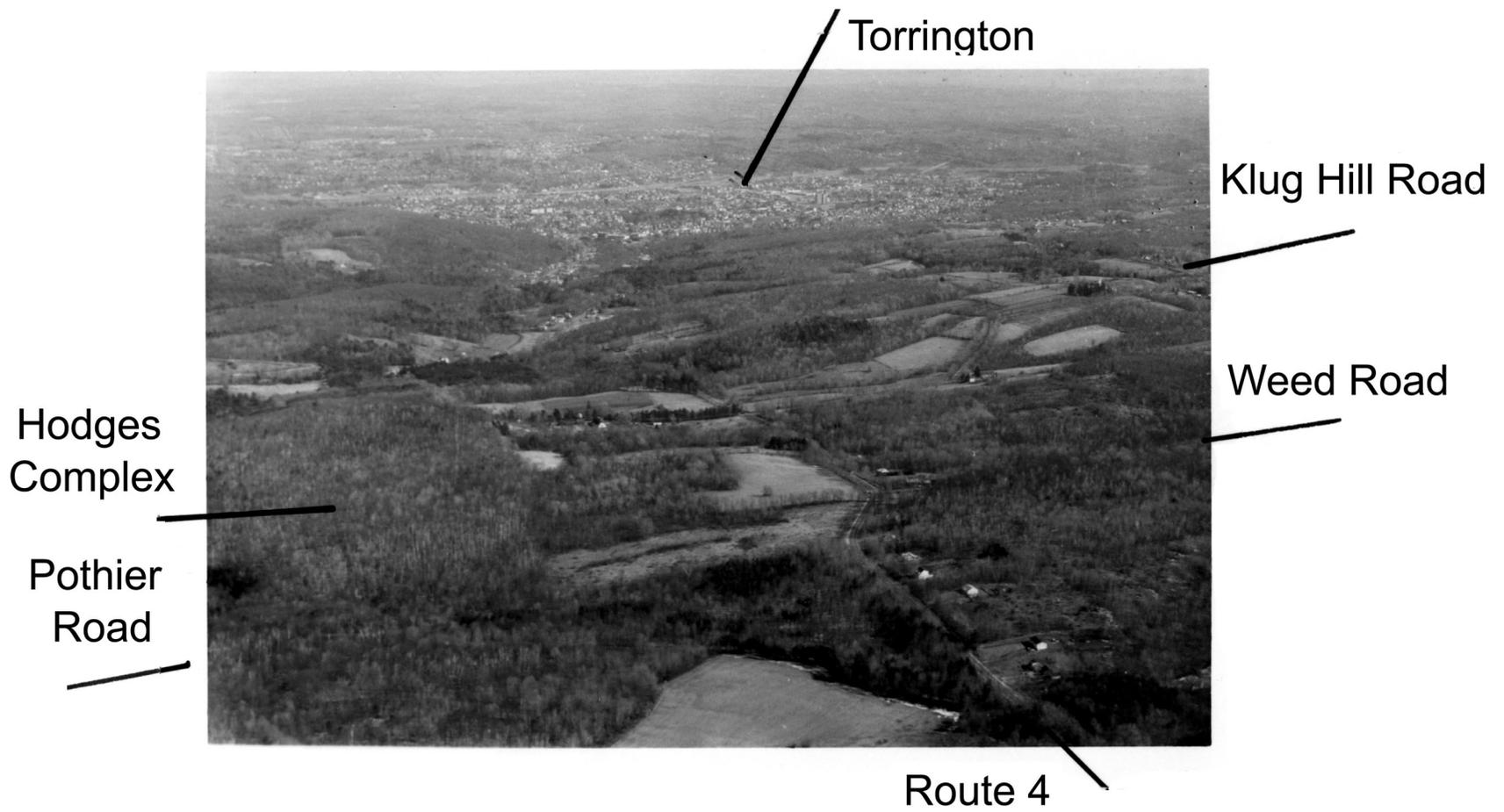


Figure 2 - Aerial view of The Hodges Complex and areas to the south and east. North is to the left of the photo.



Figure 3 – Simplified geological map of the West Torrington quadrangle. (Gates and Christensen, 1965.)

STATEMENT OF THE PROBLEM

The present study was conducted to determine the relationship of the Hodges Complex to the country rocks, to Cameron's Line, and to the regionally developed structural fabrics - topics not treated by Gates and Christensen (1965).

Detailed mapping at 1:12,000 scale was undertaken to determine if the ultramafic and mafic rocks were truly intrusive into the country rocks or whether they might be fragments of ophiolitic material tectonically emplaced along Cameron's Line. To answer these problems, particular attention was given to detailed field and petrographic examination of the country rocks adjacent to the pluton in search of contact metamorphic effects. In addition, detailed mapping of stratigraphic units in the Hartland Formation and structural features within Cameron's Line were closely examined.

From the study of microscopic and megascopic metamorphic fabrics within the Hodges Complex near Cameron's Line, and within the metasediments, it was planned to determine the relative times of emplacement of the ultramafic and mafic rocks to the formation of Cameron's Line and to successive structural episodes.

It was understood at the outset that correlation of structural events with the absolute time scale would be difficult or impossible, and primary emphasis was placed upon correct determination of the relative ages of the important events based on the superposition of intrusive and deformational fabrics.

REGIONAL GEOLOGY - CAMERON'S LINE

Precambrian rocks (p€) of the Hudson, New Milford, Housatonic, Berkshire, and Green Mountain massifs are arranged along a curvilinear trend from the southwest to the northeast, and are unconformably mantled on the east by a sequence of lower Paleozoic metasedimentary rocks (Figures 1, and 4, Plate 1). The stratigraphy of this belt, extending from the east flank of the Green Mountain Anticlinorium southward to northern Connecticut, has been traced and reported initially by Emerson (1898), and then by Doll et al. (1961), Skehan (1961), Chidester et al. (1967), Hatch, Schnabel, and Norton (1968), Cady (1969), and Hatch and Stanley (1974). It has been found that a generally eastward younging sequence of metasedimentary rocks unconformably overlie, and/or are in thrust contact with, the Precambrian rocks.

South of the Massachusetts state line, complications in structure and stratigraphy within the extension of this belt of Paleozoic rocks mark the beginning of Cameron's Line (Cameron 1951, Clarke 1958). In northwestern Connecticut, Cameron's Line is a poorly exposed trace of a major stratigraphic-structural surface that separates two dissimilar sequences of highly metamorphosed rocks - the Waramaug Formation to the west and the Hartland Formation to the east (Plate 1).

Locally, to the south of the West Torrington quadrangle, Cameron's Line marks the easternmost extent of metamorphosed Paleozoic miogeosynclinal rocks as represented by the Woodville Marble Belt (O€i on Plate 1). The nature of the Waramaug-Hartland contact has been described by Rodgers et al. (1959) and by Gates and Christensen (1965) as a major tectonic boundary, along which rocks of the Waramaug Formation or New York City Group overlie the

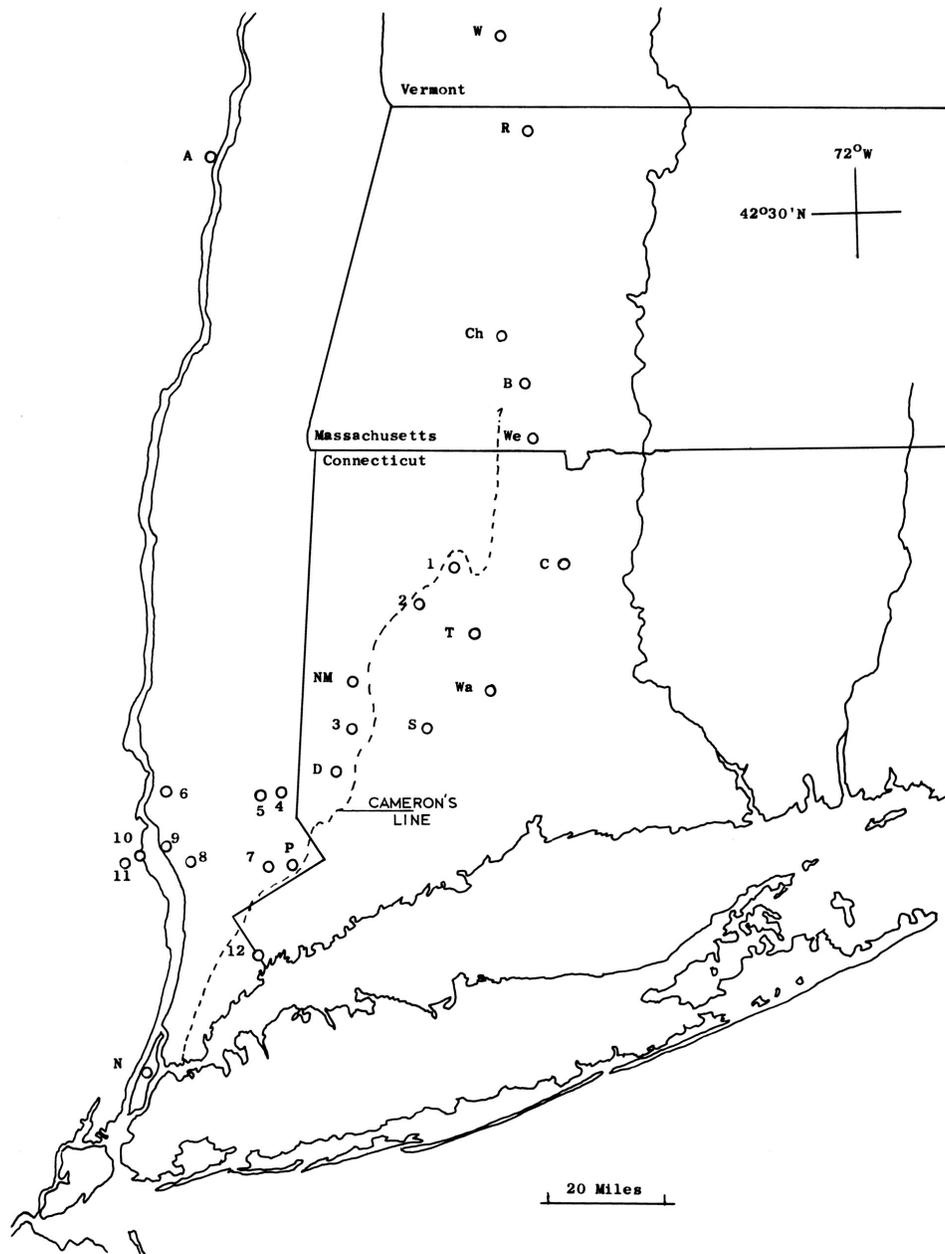


Figure 4 – Geographical distribution of localities mentioned in text.

- 1 - Hodges Complex
- 2 - Mount Prospect, Mount Tom Complexes
- 3 - Brookfield Diorite Gneiss
- 4 - Peach Lake Complex
- 5 - Croton Falls Complex
- 6 - Canopus Pluton
- 7 - Bedford Complex
- 8 - Torment Hill Complex
- 9 - Cortlandt Complex
- 10 - Stony Point Complex
- 11 - Rosetown Pluton
- 12 - Harrison Gneiss

- A - Albany
- B - Blandford, Massachusetts
- S - Southbury, Connecticut
- C - Collinsville, Connecticut
- Ch - Chester, Massachusetts
- D - Danbury, Connecticut
- N - New York City, New York
- NM - New Milford, Connecticut
- P - Poundridge Area, New York
- R - Rowe, Massachusetts
- T - Thomaston, Connecticut
- W - Wilmington-Woodford Area
- Wa - Waterbury, Connecticut
- We - West Granville, Massachusetts

Hartland Formation and correlatives from the Hodges Complex southward to New York City. Hartland rocks are found to be truncated along strike against Cameron's Line in western Connecticut.

Gates (1952) and Gates and Christensen (1965) have described shearing of rocks adjacent to Cameron's Line, and imply that shearing is causally related to abnormal strain produced by thrusting. Hall (1971) interprets the eugeosynclinal Hartland sequence in southwestern Connecticut as a Cambro-Ordovician correlative of the miogeosynclinal rocks to the west of Cameron's Line, and suggests that the contact between them is a thrust that is now overturned eastward so that rocks of the original overthrust now form the footwall block. Scott (1974) interprets the westward dipping zone as an overturned thrust contact between the Waramaug and Hartland Formations. Alavi (1975) interprets the Manhattan-Hartland Formation contact (essentially the same as the Waramaug-Hartland contact) near the Bedford Complex in the Poundridge and Mount Kisco quadrangles, New York as a thrust fault. Post-thrust deformation rotated and overturned the fault clockwise toward the west.

Farther south near Westchester, New York, Cameron's Line marks the boundary between the Hutchinson River Group (probable Hartland equivalent) on the east and the New York City Group on the west (Seyfert and Leveson, 1969).

In the vicinity of the Hodges Complex (Plate 1), the Waramaug-Hartland Formation contact is folded into a large right-handed fold, and from this point northward rocks adjacent to the extension of Cameron's Line dip steeply eastward or vertically with the Hartland Formation

and correlative rocks to the east of the Hoosac Formation (the probable stratigraphic equivalent of the Waramaug Formation). Although the Hoosac-Rowe contact is sharp and sedimentary in northern and central Massachusetts, a few miles north of the Connecticut state line the Hoosac Formation may be tectonically interlayered with graphitic schist of the Rowe Formation (Hatch, Schnabel, and Norton, 1968). Farther north in Massachusetts, Hatch (personal communication) envisions pre-metamorphic thrusts near-parallel to stratification within the Rowe that have been obliterated by later deformation.

All workers recognize that the contact off clearly eugeosynclinal rocks of the Hartland Formation or of the Rowe-Pinney Hollow further to the north with other rocks to the west is an important one. Different segments of the contact appear to have good evidence locally for a fault contact, whereas in other areas gradational or unconformable contacts have been proposed. The determination of the actual nature of this boundary is beyond the scope of this report. However, Cameron's Line may prove to be a major tectonic boundary in western New England and New York State along which important thrust faulting or underthrusting has taken place.

IGNEOUS ROCKS ALONG CAMERON'S LINE

Along the length of Cameron's Line from New York City northward through western Connecticut, and along the east flank of the Precambrian massifs in Massachusetts and Vermont, mafic and ultramafic rocks, serpentinites, mafic gneisses, amphibolites, and granitic rocks with calc-alkaline affinities crop out in association with both the Hartland and Waramaug Formations and their correlatives. The Hodges Complex is one of these plutonic masses.

Cameron's Line does seem to be the locus for plutonic igneous activity in the lower Paleozoic, although reliable absolute ages are not available to define the timing of intrusives. This belt of igneous rocks coincides in part with the belt of serpentinites noted by Hess (1955). The following discussion refers to Plate 1, although the reader is asked to refer to Figures 1, and 4 for geographical distributions of localities, municipalities and quadrangles mentioned.

The similarity between the intrusives along Cameron's Line and the "Cortlandt" type intrusives (U_i) has been noted (Hobbs 1906, Agar 1930, Cameron 1943, 1951, Ratcliffe 1970). Located south of the Hodges Complex, near Litchfield, Connecticut, is the Mount Prospect Complex. Rocks include gneissic diorite (M_i) cut by a series of related intrusives including quartz monzonite, olivine norite, quartz norite, hypersthene pyroxenite, biotite pyroxenite, and biotite hornblendite (U_i) (Cameron 1943, 1951). To the southwest in the New Preston quadrangle, the Mount Tom Complex (M_i) is chiefly a hornblende gneiss (Agar 1927, Gates 1952).

Other mafic rocks are the Brookfield Diorite Gneiss in Connecticut and the Harrison and Bedford gneisses of New York and Connecticut (Agar 1934a, b, Clarke, 1958). These rocks are very similar to the older main body of the Mount Prospect and are shown collectively on Plate 1 as M_i. Fisher et al. (1970) describe these units as biotite-hornblende-quartz-plagioclase augen gneisses with accessory garnet and sphene.

Field examination of the Bedford Complex with M. Alavi in 1975 showed such rock types as gabbro, olivine gabbro, biotite-augite-hornblendite, and orthopyroxene-hornblendite all intrusive into the main body of the Bedford Augen Gneiss. Near West Granville, Massachusetts, a dioritic-ultramafic intrusive that crosscuts the regional schistosity has been dated as 356 ± 12 Ma on hornblende using the K-Ar method (Schnabel 1975).

Many ultramafic rocks in various degrees of serpentinization have been mapped in the meta-Paleozoics leading to and including the plutonic sequence near Chester, Massachusetts (Hatch and Stanley, 1964). Mineralogically similar mafic and ultramafic intrusive rocks are found to the west of Cameron's Line in New York State. The Cortlandt Complex, Peach Lake Complex, Croton Falls Complex, Rosetown Pluton, Torment Hill and Stony Point Plutons have been recognized by various workers.

The distribution of these mafic-ultramafic rocks along Cameron's Line, their association with zones of serpentinite, and the general eugeosynclinal nature of the country rocks suggests to the writer the possibility that the intrusive rocks are ophiolitic fragments of oceanic crust. This hypothesis will be examined.

FIELD INVESTIGATIONS AND METHODS

Bedrock mapping was conducted during the period. from March 1974 to May 1976. It was found that more productive work was accomplished in the spring and fall of these years since foliage, in the summer months, masked many outcrops of bedrock. A 1:12,000 base map was employed to expand the map scale and allow for greater detail of structural elements. Field mapping was conducted using a 1:24,000 scale topographic map with woodlands, and data was transferred to the expanded scale at the end of each field day.

Roughly one half of the quadrangle (25 square miles of area) has been mapped in detail. All outcrops were visited within the field area. Linear and planar features were measured by means of a Brunton compass, and all measurements are believed accurate to $\pm 5^\circ$. Outcrops were located by pacing and, where possible, by multiple sightings of known buildings and/or topographic features. Field mapping was conducted by detailed examination of selected localities where exposures were best. Actual field tracing of contacts along strike was utilized where possible during field checking of map contacts.

Some areas of the map were given special emphasis, notably the exposures of Cameron's line, the Hodges Complex, and the Hartland Formation. The Waramaug was mapped in less detail and stratigraphic subdivision of the Waramaug away from Cameron's Line was not attempted, because the relationship of the Hodges Complex to the Hartland and to the Hartland-Waramaug boundary was of prime importance.

During the study the writer visited the following areas for the comparison of rocks traceable to the Torrington area: Blandford quadrangle, Chester quadrangle, Collinsville quadrangle, Torrington quadrangle, Cornwall quadrangle, New Preston quadrangle - (Lake Waramaug type-locality), Litchfield quadrangle, and the Bedford Complex.

Almost 300 samples from the study area were collected for laboratory study. Of these, roughly 100 were prepared for thin section investigation. Oriented samples were collected for laboratory study of the relationship of crosscutting planar features. Some of the structural elements plotted on Plate 2 were measured in the laboratory from samples of this type.

Approximately 100 samples were stained for potassic and sodium/calcium feldspars (Hutchinson, 1974). Selective staining for cordierite was conducted in study of the contact assemblages of the Hodges pluton (Boone and Wheeler, 1968). Identification of kyanite in the contact aureole was aided by grinding, heavy-liquid separation, magnetic separation, hand-picking and comparison to optical oils of known refractive index.

X-ray diffraction patterns of minerals in the contact aureole were used to confirm the presence of cordierite, kyanite, and sillimanite. Using an internal silicon standard to locate peaks, most x-ray records were run at 1° /minute with $\text{Cu}^\circ \text{K}\alpha$ radiation.

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TERMINOLOGY

Metasedimentary rock names used herein are textural field terms based on the following criterion (adapted from The Dictionary of Geological Terms, Dolphin Books - A.G.I., 1957).

Granulite - a fine to coarse grained, generally well layered rock composed almost entirely of roughly equigranular minerals such as quartz and feldspar. There is a low micaceous component with micas generally disseminated throughout the rock, rarely defining a foliation.

Gneiss - a medium to coarse grained rock composed of less than 30% micaceous minerals which are more or less oriented, giving the rock a layered aspect. The layering, composed of alternating bands of differing composition, is easily visible megascopically.

Schist - a medium to coarse grained rock composed of more than 50% micaceous minerals which are largely oriented to give a megascopic schistosity. Areas of non-micaceous minerals often separate micaceous folia lenticularly, and are generally composed of quartz and feldspar.

Relative mineral compositions are listed in decreasing amounts in the explanation to Plate 2 and throughout this paper.

II - STRATIGRAPHY OF THE METASEDIMENTARY ROCKS

Metasedimentary rocks of the Waramaug Formation (Gates, 1952) crop out west, north and northeast of the Hodges Complex, and consist largely of brown and gray weathering gneisses with minor amphibolitic gneiss, amphibolites and schists. The Waramaug gneisses are quartz rich with varying amounts of plagioclase, biotite, muscovite, and to a lesser extent garnet, kyanite, staurolite, chlorite, and opaques. Minor zones of non-mapable extent include gray hornblende quartzites, biotite schists, tremolite-quartz-calcite granulite (special symbol on Plate 2 – trem. -x).

No traceable individual. map units have been recognized within the Waramaug, in part because of complete interlayering and gradational relationships among rock types.

Metasedimentary rocks of the Hartland Formation (Cameron 1951, Gates 1951, 1952) crop out to the south and east of Cameron's Line and consist of a sequence of gneisses, schists, and amphibolites that are traceable in the study area. The lower member of the Hartland Formation consists of a 1000 foot thick sequence of gray weathering medium to coarse grained quartz-muscovite-plagioclase-biotite-garnet schist with minor ilmenite, apatite, and chlorite. Large porphyroblasts of staurolite, kyanite, biotite, and garnet are conspicuous as large knots sticking up from the foliation surface. Interlayered within the lower member is a thick sequence of amphibolite with extreme textural and mineralogic variability. In general, rocks are fine to medium grained, greenish, rusty and non-rusty weathering hornblende-plagioclase-biotite amphibolites with minor quartz, epidote, chlorite, ilmenite, sphene, and garnet.

The upper member of the Hartland Formation consists of a sequence of generally non-rusty weathering gneisses, granulites, and schists, plus layers and lenses of mica quartzite and garnet-quartz granulite. Layers of amphibolite are lithically similar to amphibolites of the lower member except for their comparatively minor development. Metasedimentary formations and sub-members that comprise the Hartland and Waramaug Formations are described in detail in the explanation to Plate 2.

The general lithologic distinction between rocks mapped as Waramaug Formation and those mapped as Hartland Formation (upper member) in the West Torrington quadrangle are summarized below:

WARAUG FORMATION	HARTLAND FORMATION
Generally brown and gray weathering, poorly bedded, granular.	Generally gray weathering, well bedded, medium grained.
Quartz and biotite are the dominant minerals present. Feldspar is deficient.	Quartzofeldspathic and muscovitic in nature.
Minor amphibolites. Where found, typically granular and gray-green to black in color.	Thick layers of amphibolite. Typically green, well foliated and highly variable. Quartzites and calc-silicates are also present.

Distinction between the Waramaug and Hartland Formation (upper member) is difficult in places but can often be made based on the guidelines presented above.

In addition, plagioclase concentrations of the Hartland Formation (upper member) often form elliptical areas visible on fresh surfaces cut across the regional foliation. The Waramaug Formation is generally indistinctly bedded, or beds are much thicker than the usual outcrop scale.

Zones of bedded material near the Waramaug-Hartland contact mapped as Waramaug Formation are presently under study, since they are more typical of Hartland rocks but clearly occur within the Waramaug terrain.

REGIONAL CORRELATION

The Waramaug Formation (Wg on Plate 1) of Gates (1952) forms a belt up to 6 miles wide from Torrington southward to New Milford, Connecticut, and is of uncertain age. The structural position suggests that it may be correlative with the Hoosac Formation of Massachusetts (Ch) as it appears to be continuous with rocks on the east flank of the Green Mountain Massif (Plate 1, Figure 4). Many workers (Hall 1971, Hatch and Stanley 1974) favor a direct correlation with the Hoosac Formation of northern Connecticut, western Massachusetts and Vermont.

The age of the Hoosac Formation (lower Cambrian and possibly Eocambrian) is based upon the fact that it is interlayered with the Rowe Schist (O_{Cr}), which in turn is traceable into fossiliferous rocks of Cambrian age in east-central Vermont (Hatch, Schnabel, and Norton, 1968).

There is a considerable gap in our knowledge of the stratigraphic relations between the Waramaug and the crystalline basement. At present it is not known whether the Cavendish and Heartwell-Readsboro rocks are correctly interpreted as occurring between the lower Paleozoic-Precambrian boundary as shown on Figure 5 (Skehan 1961, Chidester et al. 1967).

Clarke (1958), suggested correlation of the Waramaug Formation with the Manhattan Formation (OMa) near New Milford, Connecticut. To the south the Waramaug would correlate with the Lowerre Quartzite.

	Torrington quad, NW Conn interpreted by Hatch and Stanley, 1974	Rose Quad, N. Mass. Chicester et al, 1947	Wilmington-Woolford Area, Vermont Skahan, 1941	Foundridge Area S.E., N.Y. Scottford 1946	40 Km West of West Torrington, N.Y. State Map Fisher et al, 1970	W. Mass., Conn. and E., N.Y. Ten and Hartshorn, 1955 Ten, 1957 Fisher, 1970	Collinsville quadrangle Stanley 1964, 1966
Lower Devonian	Straits Schist-excluding unit in the upper Ordovician	Goshen Formation	Northfield Slate			Helderbergian Limestones	Straits Schist
Sil	Non-Deposition	Non-Deposition		Not Exposed	Not Exposed	Rondout Ls.	Calc-silicate and Quartzite
U Ord	Schist and granulite along NW contact	Hawley Formation	Cran Hill Formation	Barnard Gneiss Member		Non-Deposition	Rattlesnake Hill Formation
Middle Ordovician	Hartland Formation III	Moretown Formation	Moretown Formation	Manhattan Formation	Walloomsac Formation	Walloomsac Formation	Satan's Kingdom Formation
L Ord	Hartland I						
U C			Stowe Formation				
Middle Cambrian	Hartland Formation II	Rowe Schist	Ottaquechee Formation	Inwood Marble	Stockbridge Marble	Stockbridge Marble	Slasher's Ledge Formation
Lower Cambrian	Waramaug Formation	Hoosac Formation	Chester Amphibolite Pinney Hollow Formation	Lowerre Quartzite	Poughquaq Quartzite	Cheshire Quartzite Dalton Formation	Not Exposed
pc(?) - C	?	Cavendish Formation	Heartwell Schist	?	?	?	
Precambrian	Berkshire Massif	Not Exposed	Mount Holly Complex	Highlands Gneiss Fordham Gneiss	Undivided Gneiss	Berkshire Massif	Not Exposed

Figure 5 - Correlation chart.

To the west and northwest the Waramaug Formation would correlate with the Dalton Formation and, in part, with the Poughquag Quartzite. A major facies change is postulated to the east in the area to the west of the Collinsville Dome (Hatch and Stanely, 1974). There is no correlative to the Waramaug Formation indicated in this area.

Some modern workers (Harwood 1975, Ratcliffe - personal communication, Hall - personal communication) suggest that the Waramaug could be a transition facies that was deposited on the shelf of the lower Paleozoic North American continent alongside elastics and carbonates to the west (Cheshire, Dalton and Stockbridge Formations and correlatives). Although no evidence to prove or disprove this hypothesis has been found in the West Torrington quadrangle to date, it should be considered for discussions to follow in later sections. Alternatively, the Waramaug may be entirely older than the Hartland Formation.

The Hartland Formation (Cameron 1951; Gates 1951, 1952) consists of metasedimentary and metavolcanic rocks bounded on the west by Cameron's Line and overlain on the east by younger rocks of probable Silurian and Devonian age. Rocks mapped as Hartland extend from the Long Island Sound northward to the Massachusetts state line (Plate 1).

The lower part of the Hartland Formation (Ht, O€) is considered by Hall (1971) and Alavi (1975) to be approximately the same age as the Waramaug Formation, while others (Gates 1952, Gates and Christensen 1965, Martin 1970, Hatch and Stanley 1974) consider the Hartland to be much younger. Among those who agree to this consideration there is great disagreement as to the internal stratigraphy within the Hartland belt. A lower Paleozoic age is indicated since the

Hartland Formation is truncated by the Nonewaug Granite, dated by a Rb/Sr whole rock isochron of 382 ± 64 Ma by (Besancon 1970).

Stratigraphy of the Hartland Formation has been most confused in the past by the use of Roman numerals to denote units (Hartland I, II, III, and IV of Gates), since the proposed stratigraphic order of Hartland I (oldest) to Hartland IV (youngest) is not consistent with more recent, detailed structural and stratigraphic evidence (Hatch and Stanley 1974, Scott 1974, Stanley 1964, 1968, 1976, and this report).

Thus, on the basis of lithic similarity and stratigraphic position, Gates' Hartland units I and II are correlated with the Moretown (Om) and Rowe Formations (OEr), respectively, to the north (See Figure 5) following Hatch and Stanley (1974). They suggest that Hartland I and III are correlative, in part, although the upper part of Hartland III is considered younger than Hartland I. All Hartland rocks are younger than Hartland II (Rowe equivalent). The Hartland III is considered to be correlative, at least in part, with the Hawley Formation (Oh) of northern Massachusetts (Plate 1).

Correlations adopted for this report for the West Torrington quadrangle are shown on figure 5, and have been lithically corroborated by the writer during field investigations in adjacent areas. The lithostratigraphic position of the Waramaug Formation is still uncertain at present.

Stratigraphic correlations adopted for this report are summarized below:

Hartland I - Oh_u (upper member - Ohgr, Ohgn)

Hartland II - Oh_l (lower member - ~~€~~Ohmk)

Lithic similarity and field tracing of the Hartland Formation granulite member (Ohgr) through the "head" of the Hodges Complex eliminates the need for Hartland III (Gates and Christensen, 1965). It is suggested that Hartland rocks in the West Torrington quadrangle are correlative with the Pinney Hollow-Chester-Ottaquechee-StoweMoretown sequences of east-central Vermont and their extensions southward into Massachusetts.

III - STRUCTURAL GEOLOGY

Four major deformational events, and a weakly developed fifth one, are recognized in rocks immediately adjacent to the Hodges Complex on the basis of mapped structure, and megascopic and microscopic analysis of rock textures. Plate 3 is an axial plane-foliation map showing the trace and attitudes of sequentially developed foliations S_1 , S_2 , S_3 , and S_4 . These features are discussed in detail below and are defined on Plate 2 and Table 1.

DEFINITION OF STRUCTURAL ELEMENTS

PLANAR FABRICS

Early in the study it was found that the dominant fabric (the regional schistosity - S_2) in the metamorphic rocks was defined by oriented micas separated by quartz and plagioclase in pelitic rocks and by oriented hornblende and opaques in amphibolitic rocks of both the Waramaug and Hartland Formations.

Close inspection of the S_2 regional fabric led to the discovery of an older fabric (S_1) which is recognized in the Hartland amphibolites (€-Oha, Ohau) as a hornblende-plagioclase-epidote gneissic layering, and in the Waramaug as a foliated gneissic compositional banding. This early planar fabric is axial planar to isoclinal folds that predate S_2 .

S_1

Evidence for an early folding episode (F_1) is recognized primarily in the Hartland amphibolites where the axial planes of isoclinal M-shaped folds are seen at an angle to S_2 . S_1 , which was subsequently obliterated in most Hartland lithologies was developed axial planar to F_1 folds.

DEFORMATIONAL EVENT	LINEAR FEATURES	PLANAR FEATURES
D₁	Fold Axis (F ₁) - Isoclinal folds of compositional layering (bedding-S ₀). Lamination (L ₁) - Quartz ribbing in gneisses and schists due to the intersection of S ₁ and bedding. Hornblende lamination or streaking in amphibolites	Axial surface (S ₁) - Gneissosity in gneisses or hornblende-plagioclase gneissic foliation in amphibolites. Generally not recognized in schists.
D₂	Fold Axis (F ₂) - Penetrative isoclinal folds of the early S ₁ structures and original bedding. The axial planes of F ₂ folds are the regional schistosity. Lamination (L ₂) - Mineral streaking in schists and gneisses due to the intersection of the regional schistosity (S ₂) and the early S ₁ structures.	Axial surface (S ₂) - Regional schistosity - composed of parallel, oriented phyllosilicates developed axial planar to F ₂ folds.
D₃	Fold Axis (F ₃) - Shallow SW to NW plunging, open to tight crenulate folds of the regional schistosity (S ₂). Lamination (L ₃) - Mineral lamination due to the trace of the S ₃ cleavage on the regional schistosity.	Axial surface (S ₃) - Crenulation cleavage, slip cleavage, or spaced foliation developed axial planar to F ₃ folds. Oriented NW to WSW with generally shallow dips.
D₄	Fold Axis (F ₄) - Steep SW plunging, overturned synformal folds of the regional schistosity (S ₂). Lamination (L ₄) - Mineral lamination due to the trace of the S ₄ cleavage on the regional schistosity.	Axial surface (S ₄) - Crenulation cleavage, slip cleavage, or spaced foliation developed axial planar to F ₄ folds. Oriented approximately N20°E, 75° NW.

Table 1 - Definitions of linear and planar structural elements described in text.

The following relationships are well exposed for about 1 mile in a streambed south of Soapstone Hill Road to the east of Town Farm Road. In this area a gneissic foliation (S_1) of alternating hornblende and plagioclase \pm epidote is folded by F_2 (Figure 6). Outside of the view of the photograph the folded S_1 can be traced into the axial regions of vertical isoclines with shallow west plunging axes. Farther downstream, F_1 isoclines with an axial plane foliation (S_1) are deformed by F_2 folds and cut by a penetrative schistosity (S_1). These data suggest that F_1 was isoclinal and was accompanied by metamorphism.

The intensity of F_2 in the study area is believed responsible for the obliteration of F_1 folds and related structures in all schistose rocks. S_1 schistosity has generally not been recognized within the Hartland schists (ϵ -Ohmk, Ohgr, and Ohgn, in part). Amphibolites apparently preserved the S_1 fabric as remnants in places because they were less ductile than the schists in subsequent deformation.

South of Soapstone Hill Road and east of Weed Road there is a locality where S_1 foliation of the Hartland amphibolite (ϵ -Oha) is folded by F_2 folds. The axial planes of these folds (F_2) cut the contact of the schist and amphibolite and become the regional schistosity (S_2) when traced into the schist (ϵ -0hmk).

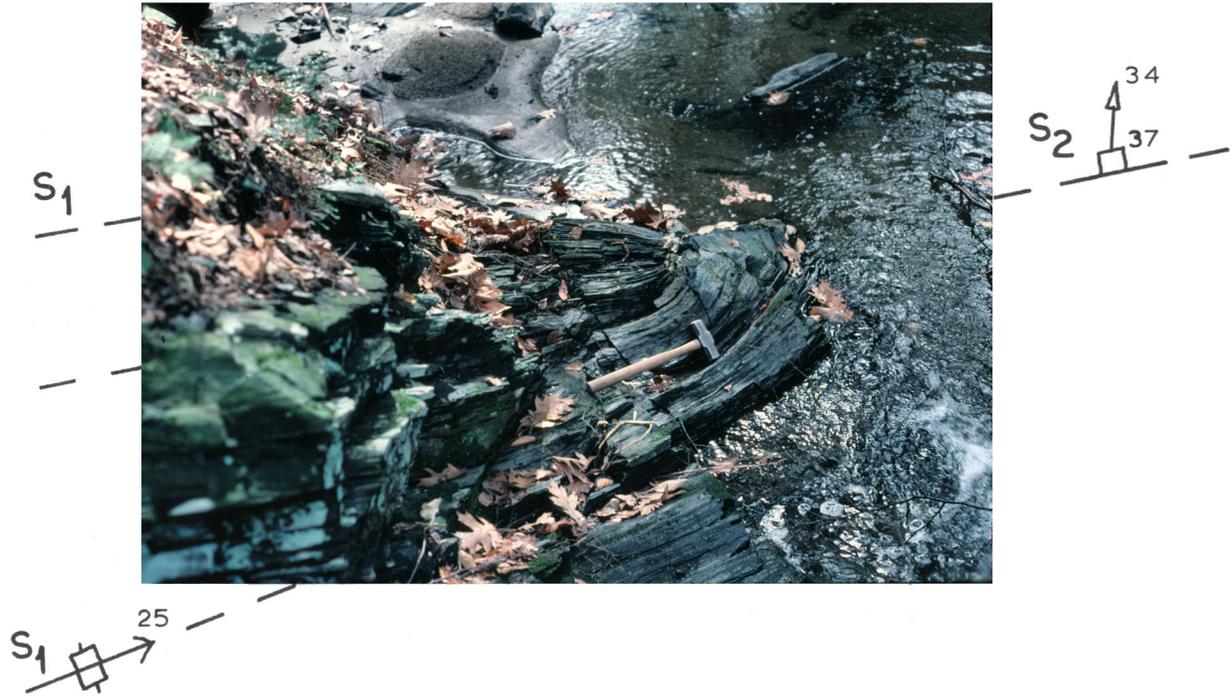


Figure 6 - Isoclinal F_2 fold of the Hartland Formation amphibolite (€ -Oha) showing the development of S_2 in axial planar relationship to folded S_1 . The S_1 schistosity bears a lineation that is also folded by F_2 . The S_1 schistosity is traceable into the axial regions of F_1 isoclinal folds just outside the view of the photograph. The hammer handle is 18 inches in length.

Direct observation of F_1 folds are limited to one locality within the Waramaug Formation. Just north of the Hodges Complex, compositional banding is deformed into near vertical isoclines with F_1 axes plunging 48° due west. The fold and axial plane (S_1) is cut by S_2 which is here characterized by neo-crystallization and rotation of micas, quartz, and plagioclase. On scattered outcrop surfaces where the actual fold is not expressed, compositional banding parallels the gneissosity (S_1). Both are cut by a schistosity S_2 , which forms a steep northeast to southeast plunging lineation (L_2).

The areal extent and penetrative character of the oldest event is difficult to determine. However, based on the mapped contacts of the amphibolite unit in the Hartland Formation with respect to the trace of the F_2 axial surfaces, it is concluded that the F_1 folds are of major significance in this area. Furthermore, the complex map pattern of the Hartland units appears to have been produced largely by the refolding of F_1 folds by F_2 (Plate 2).

The writer recognizes the possibility that S_1 may be an early metamorphic fabric that did not necessarily develop during a folding event. Such an interpretation would drastically change all geologic sections (Plate 4), revise the internal stratigraphy within the Hartland members. Based on the evidence presented above the " S_1 as axial plane to F_1 " model will be adopted.

S_1 in the Hartland and S_1 in the Waramaug Formations may have formed during the same deformational event, although there is no proof of this point. It is possible that the early foliation in the Hartland and Waramaug Formations may have formed in separate tectonic events because the sequences were placed in fault contact following the formation of S_1 in each rock as

discussed below.

S₂

A second event isoclinally refolded the schists and gneisses of the Hartland and Waramaug Formations, nearly obliterating the older metamorphic fabric in both formations and their intercalated amphibolites. It is this "secondary" fabric, generally developed at some small angle to the compositional banding, that is the easily recognized "regional" schistosity in the West Torrington quadrangle.

The trace of the regional schistosity (S₂) and the trace of Cameron's Line are parallel. Axial planes of F₂ folds (both the Hartland and Waramaug Formations) also strike parallel to the fault. The fault surface has not been observed, but it is likely that the S₂ structures parallel the fault surface.

THE WARAMAUG-HARTLAND CONTACT ---- CAMERON'S LINE

Although seldom exposed, the contact between the Hartland Formation (upper member) and the Waramaug is typically heterogeneous, consisting of rock types from both units. This zone varies from 50 feet to 200 feet and usually incorporates a cataclastically deformed amphibolite in layers 10 feet thick. Amphibolites in this zone are atypical in showing evidence of marked disarticulation of F₁ structures, and strong recrystallization of hornblende, plagioclase, ±epidote parallel to S₂. Their appearance is distinctive in comparison to amphibolites away from Cameron's Line.

This intermixed zone between the Waramaug and Hartland Formations has been traced around the "head" of the Hodges Complex. It is believed that the contact zone does not represent interbedding, since on the map scale Hartland sub-members and early metamorphic structures are both truncated along strike. Cataclasis axial planar to F_2 folds can be seen in amphibolites that occur in this zone of mixed rocks (Figures 7, 8-1, 8-2). Close examination of these photographs will show that F_2 related shear planes deform the pre-existing F_1 folds and axial planar fabrics. Early S_1 hornblende-plagioclase gneissic layering is cut by a new foliation of aligned hornblende, biotite, and lenticular quartz and plagioclase parallel to S_2 .

At the two eastern exposures of Cameron's Line in the West Torrington quadrangle the Waramaug Formation has a poorly defined cataclastic texture in outcrop, and to a lesser extent in thin section sample, up to 50 feet away from the contact with the Hartland Formation (upper member). In outcrop scale the Waramaug has a gross textural appearance suggestive of fluxion structure. Phacoidal areas appear with their long dimension parallel to the regional schistosity (S_2). In thin section (H-77,-77a) quartz is crystallized as 0.5 millimeter thick laminations enclosing small biotites that are recrystallized along and oriented parallel to S_2 . S_2 is a metamorphic fabric marked by the crystallization of oriented biotite, muscovite, and opaques and laminae of plagioclase and quartz.

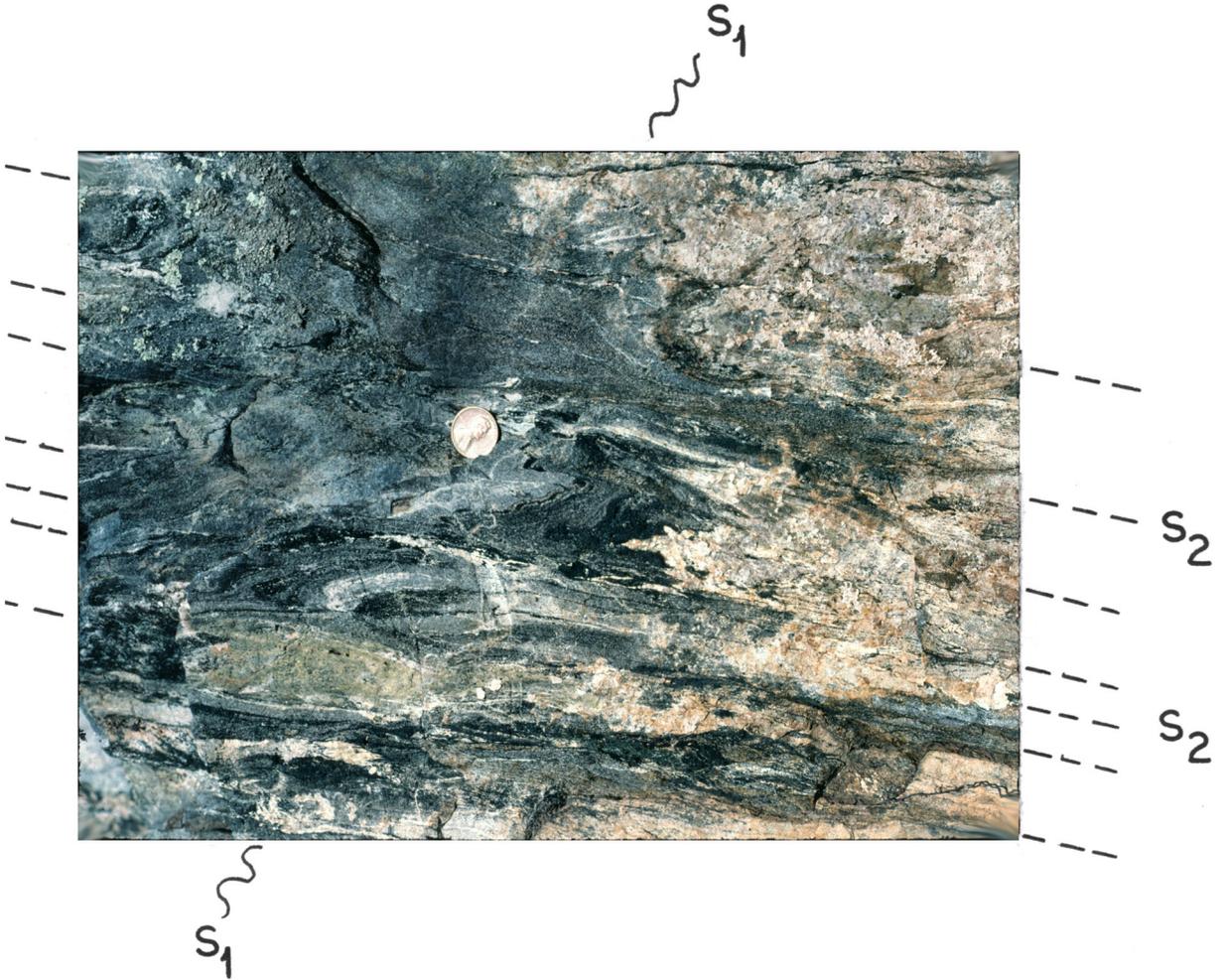


Figure 7 – Sheared amphibolite (Ohau) at the Hartland-Waramaug Formation contact (Cameron's Line) near Pattersons Pond. The early gneissosity (S_1) is transposed along S_2 shear zones near the base of the photograph.



Figure 8-1, 8-2 – Refolded F_1 isoclinal fold from the Pattersons Pond exposure. S_4 cataclastically disrupts early S_1 composed of alternating hornblende and plagioclase rich layers. S_1 is found in the axial region of the refolded F_1 fold. (Sample H-162).

The syn-metamorphic nature of the S_2 surfaces and the attendant cataclasis of the older S_1 foliation suggests that smearing out and recrystallization accompanied S_2 formation. The spatial coincidence of cataclasis, intermixed rock types and greater deformation of F_1 fabrics near Cameron's Line indicates that these intense F_2 structures formed as a result of a high strain at this boundary. These data are consistent with the hypothesis that the F_2 structures and cataclasis formed during emplacement of the Hartland rocks. Therefore the intense fabric at Cameron's Line is interpreted as a fold-thrust fabric.

Stratigraphic marker units have not been recognized in the Waramaug Formation, and for this reason the internal geometry of the Waramaug is poorly known. However as shown on Plates 2 and 4, sub-members of the Hartland Formation (upper member) are truncated against the Waramaug-Hartland boundary (Cameron's Line) in the West Torrington quadrangle. Such map data suggests that the Hartland Formation is either in fault contact with the Waramaug Formation or, alternatively, that the Waramaug unconformably overlies the Hartland Formation. In western Connecticut the Waramaug is considered older or the same age as Hartland rocks, thus forcing the conclusion that an overturned sequence of Hartland stratigraphy is in contact with the Waramaug Formation in the study area.

F_2 is responsible for the penetrative isoclinal refolding of F_1 folds and structures and is considered coeval with the development of Cameron's Line, the regional schistosity (S_2), and a second period of progressive metamorphism.

S₃

Open to tight crenulate folds, characterized by NW to WSW shallow to moderately dipping axial surfaces and by W to NW trending axes, have little effect on map pattern except locally. In regions where F₃ folds are seen, they crenulate the regional schistosity (S₂) with the development of slip planes or crenulation cleavage in the axial regions of folds (Figure 9).

Concentric folds in more psammitic lithologies and in amphibolites are observed directly next to more penetrative deformation in mica rich rocks. Less commonly an axial alignment of large (up to 3 millimeters) poikiloblastic biotites and recrystallized quartz enclose the earlier S₂ structures. Slip cleavages are still recognized away from intrusive contacts, although related folds are rarely observed. Therefore, these folds of local extent may be related to deformation formed at the walls of plutons during intrusion.

S₄

The regional schistosity was sharply folded by F₄ into folds with moderately steep SW plunging axes. A highly penetrative second slip cleavage, or spaced foliation (S₄) is generally spaced 1 centimeter or less apart in the axial regions of F₄ folds. It crosscuts all earlier tectonic features, all map units, map contacts, and Cameron's Line (Figure 10-1, -2, Plates 2, and 3).

S₄ is characterized by the growth of large poikiloblastic biotites, hornblende, and recrystallized quartz. Minute disruptions of previous minerals, the presence of deformation lamellae in plagioclase, and parallel cracks in garnet porphyroblasts are also typical of S₄. In amphibolites, preferred crystallization of hornblende, biotite, plagioclase and quartz delineate a spaced foliation. In some cases hornblendes are aligned in S₄, although generally they are not.

S₅?

A fifth deformation is suggested by the pronounced warp of the S₄ axial surface shown on Plate 3. No evidence for this fold has been recognized in the form of fold axes or planar features and therefore its existence must remain conjectural.

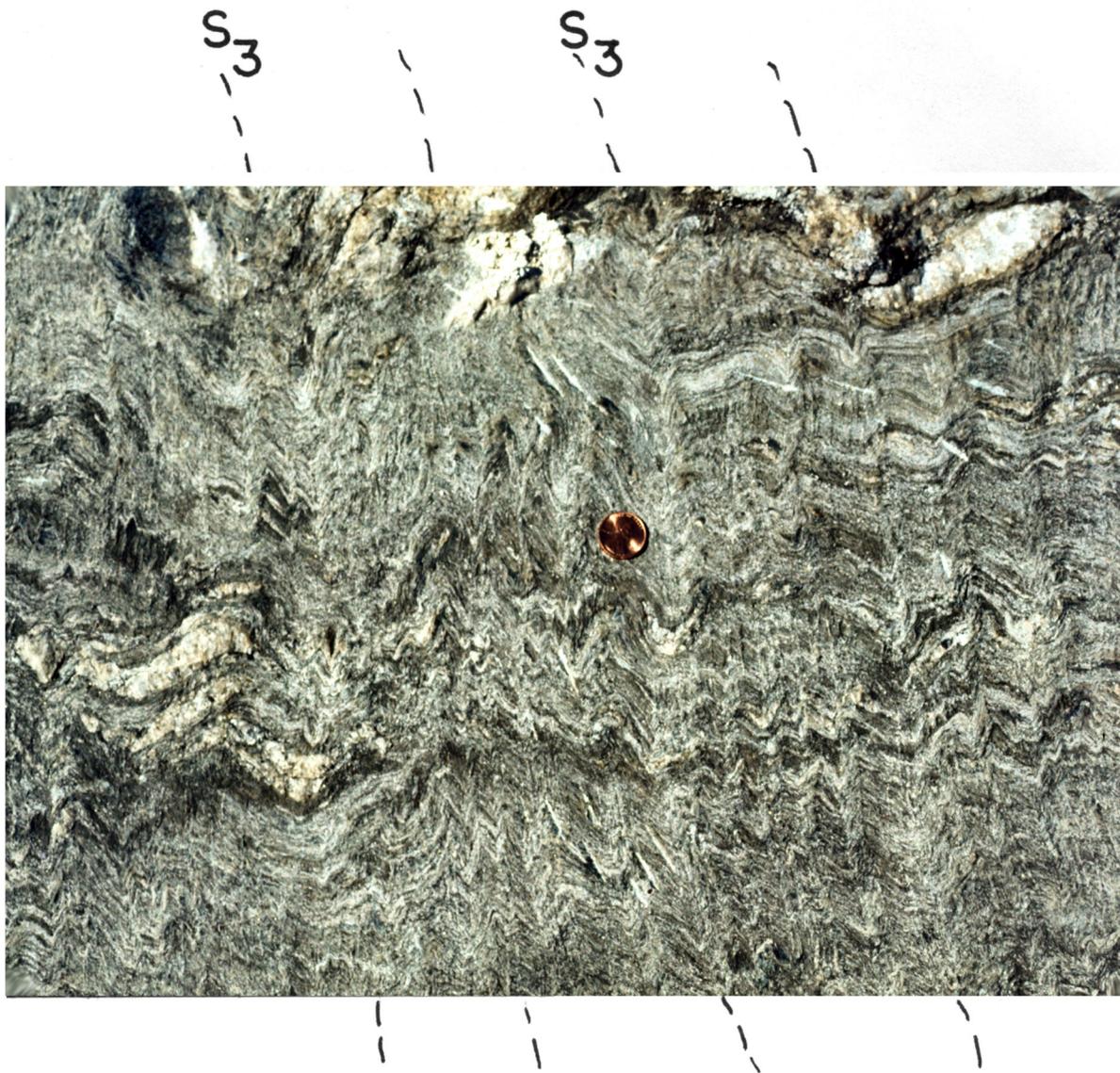


Figure 9 – Typical F₃ folds developed in the Hartland Formation (Ohgn) near the contact of the Tyler Lake Granite. Note the gentle warp of S₃.



S₂

Figure 10-1, 10-2 – Typical F₄ folds in the Hartland Formation amphibolite (C- Oha). Hammer handle is 18 inches in length and the shiny coin is a U.S. dime.

LATE FAULTS

Late normal faults are present in the study area. They occur predominately near the City of Torrington and are characterized by brittle fracture and displacement of earlier tectonic features. Near Route 4 and University Drive, a NW dipping fault striking N50°E may or may not be continuous with a fault of similar orientation in ultramafic rocks to the east of University Drive. To the west the fault fractures leuco-diorite and HarLland granulite (Ohgr). There is a component of strike-slip movement near-parallel to S₂ expressed in the elliptically fractured rocks here. The area is also cut by a N-S trending, W dipping normal fault that cuts the previously mentioned fault near Allen's Dam. It is suggested that early brittle fracture took place during the F₄ flexure, since faults are not on strike with "typical" Mesozoic faults in the study area and elsewhere in the region.

A small reverse fault northwest of the Hodges Complex underlies a thin intermittent stream and has expressed offset in the Waramaug-diorite contact. Such faulting could be related to late compression in the hinge area of F₄.

A fault trending N20°W, and dipping 75° SW cuts across early isoclinal folds and appears to be the structural control for the presence of Stillwater Pond. Studies of offset in the adjacent Waramaug Formation indicate that the Stillwater fault is normal. Plates 2 and 4 should be consulted for movement senses on these fault surfaces.

STEREOGRAPHIC ANALYSIS OF MAJOR MEGASCOPIIC FABRICS

Figure 11 is designed to show the spatial relations of the major structural elements described above. Stereonet #1 shows poles to the regional schistosity (S_2) of both the Hartland and Waramaug Formations and their sub-members. The wide scatter of points supports the existence of post- S_2 deformation. The actual distribution shows a broad area of concentration of poles in the eastern half of the net. It is suggested that F_3 folding is responsible for the broad eastwest scatter and that F_4 folding is responsible for the prominent scatter along the NW-SE girdle. Such distribution would be expected as poles to S_2 were rotated into a plane perpendicular to F_4 .

Stereonet #2 shows poles to S_1 , of both the Hartland and Waramaug Formations and their sub-members. Stereonet #3 shows F_4 fold axes and L_4 lineations (L_4 was measured from the intersection of S_4 and S_2 on rocks in the field and calculated from oriented hand samples in the laboratory). Most of the 23 plotted points are lineations.

A combined diagram (Stereonet #4) of F_4 axes and lineations, and S_4 shows a consistent grouping of poles to S_4 (average axial plane drawn in) and a consistent location of F_4 within its axial plane. L_4 lineations plotted in the northern half of the net are due to intersections of S_4 and the north dipping, regionally foliated rocks north of Cameron's Line. F_4 then, trends approximately $S50^\circ W$ and plunges $60^\circ SW$ with an axial plane oriented $N19^\circ E$, $72^\circ NW$.

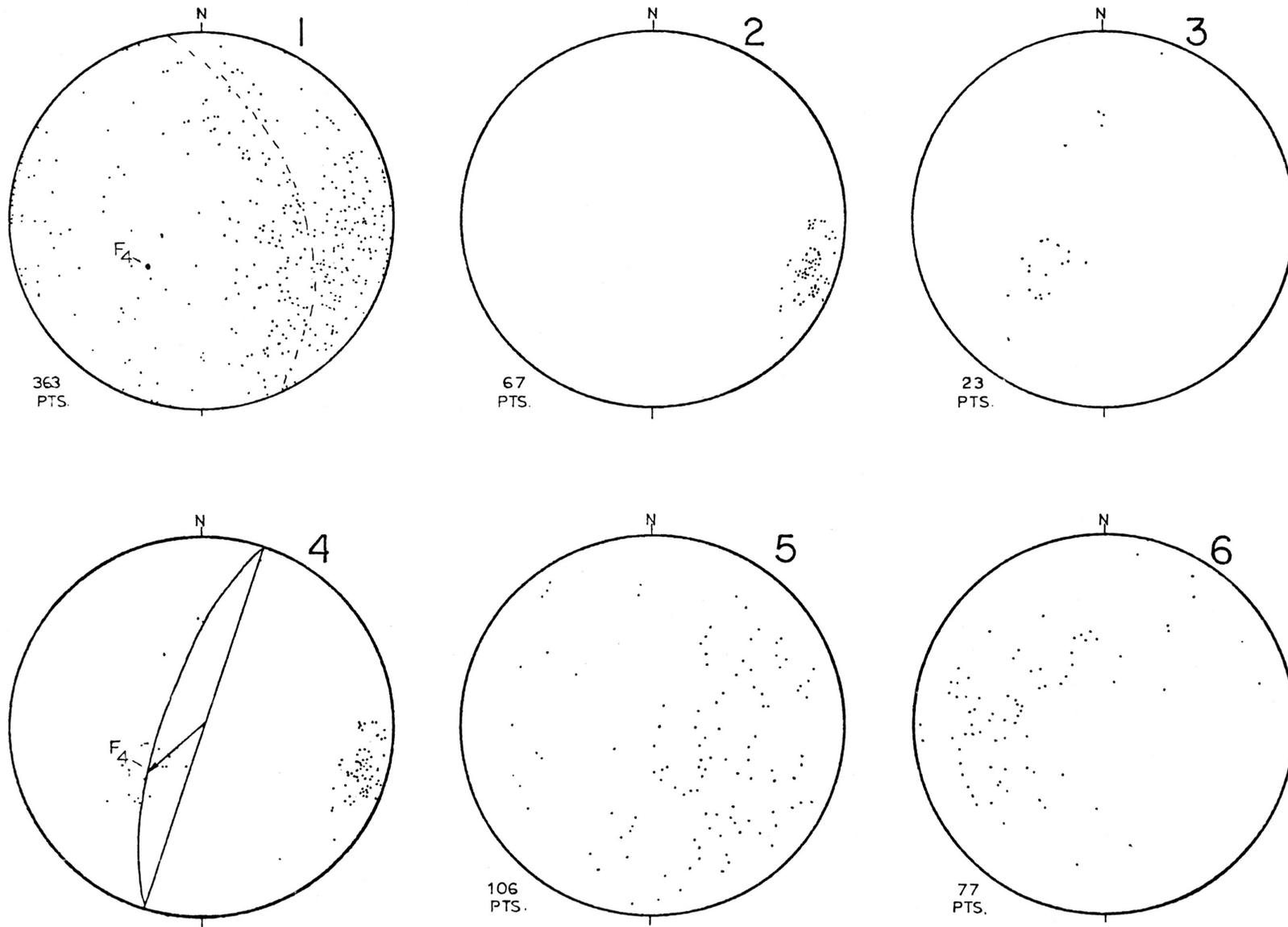


Figure 11 – Orientation diagrams of structural features.

Stereonet #5 shows poles to the axial planes of F_3 folds and S_3 slip cleavage of both the Waramaug and Hartland Formations. F_3 has been interpreted as syn-intrusive defoliation at the walls of the Hodges Complex and the Tyler Lake Granite. The pronounced scatter of points in the eastern half of net #5 do not fit any one great circle as would be expected if S_3 were statistically parallel and deformed by F_4 only. L_3 lineations (measured on the regional schistosity, S_2) and fold axes of F_3 folds are dispersed as shown on stereonet #6 and define two poorly developed great circle paths. The explanation for the scatter on nets #5 and #6 could be: (1) that there was a sampling bias with most measurements made on the east flank of F_4 , near the Tyler Lake Granite, and (2) that since S_3 formed in response to local stress fields at the margins of plutons it should not be statistically planar because the plutons have irregular margins. The scatter of poles to S_3 , F_3 axes and lineation is poorly understood but could be inherent in their formation.

STRUCTURE SECTIONS

The following discussion relates to metasediments only. Igneous rocks will be treated in later sections. Sections were drawn to be consistent with the surface data and to the axial traces shown on Plate 3. The axial surfaces are also shown in sectional view on Plate 4. The S_1 axial traces on Plate 4 were left intermittent after many hours were spent in an attempt to imagine the extrapolated, continuous S_1 traces and their relationship to trap plan and structure sections. Although scores of models were studied to explain "suggested" F_1 axial traces and their relation to Plates 3, and 4, it was finally decided to leave S_1 as intermittent as traceable in the field and to draft sections to be consistent with the partial but real traces of S_1 . A paucity of data made any extended investigations of the earliest structural fabric shear speculation and therefore sections were drafted to be consistent with the presented data. The existence and importance of F_1 folding has been verified, as argued earlier, by field observation of crosscutting fabrics and direct observation of early folds and lineations, but the exact configuration of F_1 closures in the subsurface is uncertain.

The major structure in the study area is a late dextral synformal fold (F_4) that warps the regional schistosity (S_2), an earlier fabric (S_1), the Waramaug-Hartland boundary, and the Hodges Complex (Plates 2, 3, and 4). The fold has a steep western limb (vertical to overturned in places) and a shallow west-dipping eastern limb. The axial plane of this fold trends NNE and dips steeply toward the NW with axes trending SW and plunging 50° to 60° . North of section C-C' (Plate 3), plunges for F_4 are northward (as measured on S_2). These relations are due to interference on the north dipping regional schistosity in this region.

Section D-D' shows the relation of the early S_1 surfaces to formational contacts, S_2 , and S_4 rather clearly. The isoclinal refolding of F_1 structures by F_2 and the refolding of the S_1 - S_2 complex structure by F_4 into an overturned synformal fold is shown. Of particular interest is the truncation of Hartland Ohgn against Cameron's Line, the attitude of S_2 parallel to Cameron's Line, and that S_4 cuts all early planar features, map contacts, and Cameron's Line. A component of net slip of the thrust into the section away from the viewer is suggested. The major F_1 - F_2 structure is believed to root downwards and is truncated by Cameron's Line and the Tyler Lake Granite.

Section E-E' shows the convoluted nappe of Hartland rocks in longitudinal view. The truncation of Hartland sub-members against Cameron's Line is pronounced as is the parallel orientation of S_2 and Cameron's Line. The effects of F_1 , are not evident since the section is near parallel to S_4 . In this view the thrust direction is almost entirely away from the viewer into the line of section.

Since F_4 has severely warped all structures a simple rotation of the S_1 - S_2 major structure about F_4 , would suggest that material originally was thrust from the east as a series of isoclinal folds (F_1) that were re-deformed as they were emplaced (F_2).

IV - THE META-IGNEOUS ROCKS

Metamorphosed intrusive rocks of mafic and ultramafic affinity are widespread in the Hodges Complex and are

Hornblende Orthopyroxenite	Porphyritic Hornblende Diorite
Hornblende Gabbro	Hornblendite
Biotite-Tremolite-Orthopyroxenite	Serpentinite
Hornblende Diorite	Biotite Hornblendite
Orthopyroxene Hornblendite	

Thus a greater variation in igneous rock types is now recognized compared with Gates and Christensen's study which only mentioned hornblende gabbro, hornblendite, and transition-gabbro-amphibolite rock.

These rock types are largely found within a roughly 1 square mile area known as the Hodges Complex. A central area (Plate 2) and other scattered discontinuous areas of pyroxenite and hornblendite are in contact with gabbroic rocks, and surrounded by flow layered dioritic rocks.

Geologic sections of the Hodges pluton are shown on Plate 4. Pegmatites have been omitted for clarity. This pluton is similar in pattern to other stocklike ultramafic plutons such as the Union Bay (Ruckmick and Noble, 1959) and Duke Island (Irvine, 1963) complexes. The Hodges Complex is interpreted as a steep walled, folded, mushroom-shaped pluton with a core of hornblende gabbro and a dioritic chilled border. Mafic and ultramafic types form a stock-like central intrusion that crosscuts the gabbro-diorite mass.

The pluton is in direct contact with both the Waramaug and Hartland Formations and is surrounded by a narrow contact aureole developed within these rocks (treated in section V on metamorphism).

Gates and Christensen argue that the rocks of the Hodges Complex and amphibolites stretching to the south are co-genetic and that the amphibolites are sill-like intrusions stemming from the head of the pluton (Figure 3). This suggestion will be examined.

LITHOLOGY

Hornblende gabbros and hornblende diorites are difficult to distinguish in hand sample even though most rocks are coarse-grained. Field distinction was primarily made on the basis of hornblende content though it was found that such a classification was erroneous in the light of petrographic research. Therefore, separation of gabbros and diorites were made on the following criterion:

Gabbros were so termed if plagioclase compositions exceeded An₅₀ (determined by the Michel-Levy method) or if suggestions of pyroxene ghosts were found in hornblendes present. Plagioclase was often found to be clouded, zoned and abundantly twinned in gabbroic rocks.

Diorites were generally finer grained, contained non-zoned, generally poorly twinned plagioclase with compositions less than An₅₀ (where measureable), and showed little to no evidence of relict pyroxene. Quartz is sometimes a minor constituent.

Distinction between pyroxenites and hornblendites was made according to the dominant mineral present. Rock types were named on the basis of mineral percentages according to Streckeisen (1973).

Detailed descriptions of lithology, mineralogy and field appearance occur in the explanation to Plate 2 and are discussed in the following pages.

IGNEOUS AND METAMORPHIC TEXTURES AND MINERALOGY

All rocks of the Hodges Complex have been metamorphosed. In thin section, changes to foliated textures and replacement of such igneous minerals as olivine, enstatite, hypersthene, augite, and hornblende by tremolite, actinolite, anthophyllite, cummingtonite, hornblende, magnesium chlorite, calcite, serpentine minerals, and talc are widespread.

Gabbros and diorites remain relatively unaltered although corrosion and recrystallization of plagioclase and hornblende and the growth of chlorite and biotite are noted.

Pp - META-PYROXENITE, HORNBLENDE

No attempt to subdivide these types were made in this study and all rocks consisting of less than 10% plagioclase were grouped together as (Pp).

Hypersthene pyroxenites are found with various amounts of hornblende that appears to be of igneous rather than metamorphic origin. However, relatively unaffected pyroxenites have been observed. Typically, hornblende forms green poikilitic, nonoriented crystals up to 1 inch across. The hornblende gives rocks a spotted appearance when grain size is smaller, and a mottled, pegmatitic appearance as grain size increases. Sphene is found to rim magnetite due to the dissociation of ilmenite - a common mineral in both the meta-igneous and metamorphic rocks of the region. Patterns of opaque dusts suggestive of pyroxene and olivine outlines are not uncommon within the large green hornblendes. Exsolved opaques in the cores of hornblendes have also been noted. Textures of this kind are present in igneous rocks, and especially peridotites from stock-like bodies as described by Wager (1968).

Ultramafic rocks have a distinctive cleavage in outcrop in some exposures. In particular in the axial regions of F₄, there is a marked increase in the development of colorless amphiboles. Where found, hypersthene is rimmed by oriented, twinned cummingtonite, and in other places by such metamorphic minerals as anthophyllite, tremolite, and actinolite.

The ultramafic (to the west of Weed Road under the powerline) consists of a coarse grained to pegmatitic hypersthene hornblendite with mottled, poikilitic hornblendes up to inches in size. Tremolite, magnesium chlorite, calcite, and opaques are also present. Chlorite mats on weathered outcrop surfaces tend to impart a silvery appearance although the rock is typically brown and gray-green weathering and silver-green on fresh surfaces.

Hornblendites often contain up to 98% hornblende with a trace of plagioclase and sphene. Relict enstatite has been observed (Sample H-33). Traces of biotite, chlorite and opaques are recorded from a similar rock (Sample H-37). Biotite often has a red-brown color due to the high titanium content while in other instances it occurs in replacement relationship to hornblendes present.

The 1320' hill to the southwest of the intersection of Route 4 and Weed Road is chiefly underlain by hornblendite and hornblende gabbro with minor diorite intrusive into and crosscutting the Waramaug-Hartland contact. Small zones of porphyritic hornblende diorite can not be mapped because of poor exposure. Mafic layers consisting of green hornblende (poikilitically enclosing pyroxene) occur in 6 inch bands parallel to the flow layering of gabbroic rocks. Elliptical plagioclase rich segregations are stretched within the flow layering and are

abutted by hornblende crystals. Apatite, zircon, sphene, and quartz are found as trace minerals while the major minerals present are hornblende (green and opaque rich), plagioclase (cloudy, zoned, relatively high An content), and minor biotite (red-brown color). Opaques such as magnetite, ilmenite, and various iron-nickel sulphides occur in pyroxene rich rocks, and often in remarkable concentrations.

Hg - HORNBLLENDE GABBRO

Hornblende gabbros also show evidence of pyroxene ghosts although clearly the original pyroxene content was minor. Plagioclase (Labradorite An_{50-55}) is generally clouded with oscillatory zoning. Hornblende and plagioclase occur in roughly equal amounts (near 50% each in volume), biotite (up to 5%), traces of opaques, apatite, sphene, chlorite, and more rarely quartz.

Gabbroic rocks with a well preserved igneous texture consisting of subhedral hornblende and plagioclase predominate on Klug Hill where rocks are coarse grained with plagioclase mildly subordinate to hornblende.

Post intrusive metamorphism had little effect in the central cores of intrusives where igneous habits are generally preserved. In other areas, recrystallization of hornblende and alignment of biotite with parallel development of deformation lamellae in plagioclase are noted.

Di - HORNBLLENDE DIORITE

Dioritic rocks are by far the most variable texturally and mineralogically in The Hodges Complex. They are a heterogeneous mass of greenish to black and white, poor to well foliated, fine to medium grained, flow layered rocks. Green hornblende and plagioclase are the major minerals as in gabbroic rocks, with a 1% to 5% biotite component. Traces of epidote, sphene, opaques, quartz, apatite, and chlorite are also present. Hornblende crystals have opaque dusts within them that are suggestive of pyroxene outlines (although entirely replaced now by hornblende) and plagioclase exhibits oscillatory zoning. Biotite retrogression, late stage iron oxide veins, polygonized plagioclase, ilmenite rimmed by sphene are other observed relationships. In general, as in gabbroic rocks, hornblende predominates over plagioclase.

Alternating layers composed of sub-parallel subhedral laths of hornblende and subhedral to euhedral laths of plagioclase are interpreted as igneous flow layering.

Opaque rich fine grained dioritic rocks occur as a 100 foot thick belt between observable ultramafic and Hartland rocks, near the powerline-Weed Road intersection mentioned earlier. The diorite is foliated and garnet enriched. Garnet decreases rapidly from the contact area where diorite and Hartland rocks occur in a lit-par-lit 30 foot zone. Mineralogically, green hornblende (rich in opaques), is more abundant than plagioclase. Opaques, biotite, and quartz each equally comprise the remaining 15% of the rock.

RELATIVE AGES AND INTRUSIVE NATURE OF THE HODGES COMPLEX

The Hodges Nickel Prospect¹ is situated to the northeast of the largest remaining concentration of ultramafic rocks in the West Torrington quadrangle. The northeast border of this mass is sheared and serpentized, perhaps due to younger faulting, where it is in contact with the Hartland Formation (Ohgr). Ultramafic rocks here crosscut foliated amphibolite (Ohau). Hornblende gabbro is in chilled contact with both the amphibolite and Hartland (Ohgr) rocks.

At the Hodges Mine, hornblende gabbro is in flow oriented, chilled contact with sulphide-rich hornblende pyroxenite. A 6 inch pod of ultramafic material is incorporated in a coarse grained hornblende gabbro to the southeast of the Hodges Mine, and chunks of ultramafic rock are within a dioritic chill zone that becomes medium grained a few feet from the contact.

Along the 1200' ridge to the south of the Hodges Nickel Prospect dioritic and gabbroic rocks of extreme textural variability are observed to include pods of hornblende in some places (Figure 12). Another in situ observation shows angular and perhaps brecciated chunks of ultramafic rock, some up to a cubic foot in size, enclosed in hornblende gabbro. This consistent relationship (about 10 similar observations) of xenoliths of ultramafic rock within the hornblende gabbro would suggest a sequential intrusion of more mafic to less mafic types (Pp to Hg).

¹ - The interested reader should consult Agar (1930) for a description of sulphide-silicate relationships in rocks of the Hodges Nickel Prospect.



Figure 12 – Hornblendite inclusion in hornblende gabbro. Specimen is from the southern portion of the Hodges Complex.

Evidence for an alternate intrusive hypothesis of hornblende gabbro (oldest) to ultramafic rocks (youngest) is primarily based upon the geometric relations in the map pattern (Plate 2). Ultramafic rocks (Pp) crosscut contacts of gabbro and diorite and truncate flow layering. It is suggested that contradictory inclusion textures could be due to intrusion of a partially solidified crystalline mush of ultramafic rocks into a still heated gabbro-diorite composite pluton. At the borders, coherent masses of ultramafic rock were locally injected as "zenoliths" into older, pre-existing mafic rocks (Hg and Di).

EVIDENCE FOR AN IGNEOUS ORIGIN OF THE HODGES COMPLEX

Many field observations suggest an igneous origin for rocks of the Hodges Complex. In areas, up to 20 foot screens of Waramaug and Hartland (upper member) rocks are oriented with their long dimension parallel to the flow layering of the Hodges diorite (Di). The flow layering, which is composed of alternating parallel trains of subhedral to euhedral hornblende and plagioclase, in most cases parallels the regional schistosity (S_2) of the enclosed metasediment although clear crosscutting relations are locally encountered. In one area north of Route 4 in the streambed to the east of Pothier Road, contacts between diorite and the Waramaug Formation are typically lit-par-lit in transition zones up to 50 feet wide across strike. Anastomosing dikes 1 inch to 4 inches in thickness of identical composition crosscut flow layering of the diorite.

Zenoliths and screens of metasedimentary rocks are common and are found in all major rock types of the Hodges Complex. Zenoliths of igneous rock are often found within the borders of adjacent plutons. In addition Hodges rocks are observed in chilled contact with regionally foliated (S_2) metasediments, and each other, and flow layering and anastomosing dikes have been observed in the dioritic rocks. Ultramafic and mafic rocks are generally not flow layered

although such layering has been noted in both lithologies at a few localities.

These observations, the recognition of igneous textures of subhedral to euhedral mafic minerals, oscillatory zoned plagioclase, and typical igneous reaction relationships, plus the fact that a contact aureole has been detected adjacent to the Hodges Complex forces the conclusion that the Hodges Complex is in fact igneous and that intrusion post-dated the development of the regional schistosity (S_2).

Earlier it was argued that S_2 is the fold-thrust fabric developed during the formation of Cameron's Line. The structural position of the Hodges Complex, as shown on Plates 2 and 4, indicates that the pluton was intruded across Cameron's Line. The existence of post-intrusive deformation and metamorphism suggests that the Hodges was deformed by the F_4 synformal fold rather than being intrusive into the core of the flexure, as had been previously suggested (Gates and Christensen, 1965).

THE RELATIONSHIP OF THE HODGES COMPLEX TO THE HARTLAND AMPHIBOLITES

The suggestion that amphibolites are related to the igneous rocks at the "head" of the Hodges Complex requires examination. From the map pattern (Plate 2) the Hodges Complex is not in actual contact with the amphibolites except where screens and xenoliths of Hartland rocks are engulfed by Hodges rocks. Gates and Christensen (1965) realized that there was a problem in that the amphibolites are structurally concordant to and bear the regional schistosity (S_2 of the present study), while mafic and ultramafic rocks of the "head" of the complex enclose regionally foliated rocks.

They have noted (pp. 18-24) that textural changes and mineralogic distinction is notable between the massive gabbro to the north (unit "hog"), the transitional rock (unit "hot"), and amphibolites (unit "hoa"). Figure 13 is a comparative modal analysis of rocks of the gabbro and amphibolite (units "hog" and "hoa") in which differences in the relative amounts of epidote, biotite, and quartz are noted. Plagioclase compositions differ in that amphibolite plagioclase is in the An_{24-40} range compared to labradorite compositions in the gabbroic rocks. Also, the hornblende of the amphibolite is deeply pleochroic, opaque poor, has a prismatic habit and generally lies within the regional schistosity. Gabbroic hornblende is generally subhedral to euhedral, tabular in habit, and includes considerable opaque minerals. These observations would suggest a metamorphic origin for the amphibolitic rocks.

	Hornblende gabbro ¹		Amphibolite ²	
	Range	Mean	Range	Mean
hornblende	48.2–60.6	54.7	47.6–70.2	59.5
plagioclase	21.2–34.6	26.5	19.8–29.0	26.3
biotite	9.8–20.2	13.5	0.0–1.3	0.4
opaques	0.6–6.2	2.7	0.1–2.4	1.3 ³
quartz	0.0–3.4	1.7	0.6–11.6	3.8
sphene	0.2–1.8	0.9	0.0–2.0	0.4
epidote	—	—	0.0–21.2	7.3
accessories	—	—	0.0–5.8	1.0 ⁴

¹ Based on modal analyses of 9 samples, 1,000 points each

² Based on modal analyses of 14 samples, 2,000 points each

³ Ilmenite

⁴ Chlorite and pyrite

Figure 13 – Modal analyses of the Hodges Mafic Complex. (From Gates and Christensen, 1965, p.19.)

The writer finds no textural or mineralogic evidence to suggest a transitional rock type but rather finds Gates and Christensen's description of {"hot" not different from rocks snapped as diorites (Di) in the present study. The mapped distribution of dioritic ("Transitional") rock clearly shows that the diorite represents a border phase of the main gabbroic mass and does not occur in any of the tentacles shown by Gates and Christensen.

In addition, since within the contact aureole of the Hodges Complex hornblende is found to overgrow the regional schistosity (S₂) of the Hartland amphibolite (Ohau), the writer suggests that the Hodges Complex is younger and not related to polydeformed Hartland amphibolites (C-Oha, Ohau) to the south. These data clearly show that the amphibolitic rocks in the Hartland south of the complex are not logically connected with the intrusive.

Tg - THE TYLER LAKE GRANITE

The Tyler Lake Granite is in intrusive contact with all units of major extent (with the exception of the Hartland Formation lower member - €-Ohmk) suggesting a young age for this mass. In thin section sample the Tyler Lake Granite is composed of:

Quartz (35%) as large, anhedral interstitial crystals, slightly strained with a very small 2V.

Microcline (30%) as anhedral, interstitial crystals (slightly larger than quartz) with wavy extinction.

Plagioclase (15%) as subhedral crystals with pericline twins.

Muscovite (10%) is clear with two lineations in thin section.

Biotite (2-5%) sometimes occurs at the borders of muscovite crystals or as discrete crystals. Both biotite and muscovite define the planar S_4 direction.

Garnet (2-5%) as euhedral to subhedral crystals, clear with moderate relief.

Chlorite (trace) as a minor retrograde after biotite. (Sample H-50, H-51)

Gates and Christensen, (1965) report (p. 30):

Quartz (37%)

Plagioclase (23%)

Microcline (27%)

Muscovite (10%)

Biotite 3%

Based on 12 samples or 15,000 total points.

In the field granite is observed to intrude into the axial regions of F_3 folds near Lovers Lane Road and is deformed into 30 foot to 50 foot boudins whose boudin line coincides with F_3 axes. Exactly similar relations were found about a mile to the south. In places granite is observed to incorporate 10 foot to 20 foot block of foliated country rock, occupy F_3 fold crests, enclose regionally foliated amphibolite (p€-Owga) of the Waramaug Formation, crosscut flow banded dioritic rocks, and crosscut early structures in both the Waramaug and Hartland Formations.

The contact of the Tyler Lake Granite and ultramafic rock is quartz rich with a plethora of euhedral hornblendes radiating into the granite, away from the ultramafic. At the same locality pieces of ultramafic rock are within the granite.

In some places the Tyler Lake appears dioritic and consists of hornblende and biotite in addition to its typical mineralogy. Although this field occurrence is rare (three localities), field evidence suggests that this leuco-dioritic type preceded the major influx of the Tyler Lake Granite. Both have been deformed by F_3 folds.

The Tyler Lake Granite, which is of extreme textural but limited mineralogic variability, is the result of continuous pulses of material post-dating the hornblende dioritic intrusives of the Hodges Complex but pre-date or are syn-tectonic with respect to F_3 folds.

p – PEGMATITES

Pegmatitic rocks, exclusive of those mapped and described as Tyler Lake Granite, typically consist of varying proportions of albite, microcline, quartz, and muscovite with local concentrations of ilmenite, black tourmaline (schorl), and more rarely beryl and garnet.

The pegmatite body near Pattersons Pond is in contact with the Hartland Formation (Ohgn). At the contact, a xenolith of Hartland gneiss is not deformed although the plane of contact and the Hartland are deformed by a reclined fold (F_3) with a near horizontal axial plane.

Pegmatite sills and dikes contact and intrude the schistosity of the Hartland Formation (lower member - €-Ohmk) and its amphibolite (€-Oha.). In another place, tourmaline occurs as a fine matting within the schistosity of the Hartland Formation (€-Ohmk). Aplite dikes are common. They generally cut all pre-existing structures.

Contact relations are both concordant and discordant with respect to the regional schistosity (S_2) with most pegmatites exhibiting a faint shear or micaceous foliation as an S_4 fabric.

SUMMARY OF IGNEOUS ROCK RELATIONSHIPS

Field mapping and studies of contact relations, igneous and metamorphic mineralogies and textures, and contact metamorphic effects of the Hodges Complex have shown these rocks to be of intrusive origin. The similarity between igneous and metamorphic minerals in the major rock types suggests a co-magmatic origin for the igneous rocks.

Time spans between gabbro and diorite appear, less than between ultramafic and mafic types, since sharp contacts of ultramafic and mafic types give way to filmy, mixed areas where gabbro and diorite are in intimate contact. The Hodges Complex was intruded as a series of plutons of differing composition with diorites interpreted as the wall rocks of the initial gabbroic intrusive. Field evidence and map pattern (Plate 2) indicates that magmatic intrusives were injected in this somewhat oversimplified order: pyroxenites and hornblendites (youngest) - gabbro and diorite (oldest).

Igneous flow layering in diorites and at the borders of gabbroic rocks is defined by alternations of sub-parallel laths of hornblende and plagioclase. This planar feature is generally parallel to the regional schistosity of the intruded metasediments.

In the more mafic types (Pp, Hg) primary igneous minerals such as olivine, hypersthene, enstatite, augite, and hornblende are partly replaced by metamorphic minerals such as tremolite, actinolite, anthophyllite, cummingtonite, hornblende, biotite, chlorite, serpentine, and talc.

Contact induced recrystallization of polydeformed Hartland amphibolite (Ohau) and contrasts in modal mineralogy and texture between the rocks indicates that intrusives to the north are younger and not genetically related to Hartland amphibolites.

With respect to structural deformation of the country rocks, the Hodges Complex was intruded after the development of the regional schistosity since flow oriented intrusives include regionally foliated rocks and contact minerals enclose S_2 structures.

Rocks of the Hodges Complex are metamorphosed and sheared along a 50 foot to 200 foot wide zone that is parallel in orientation to the axial plane of F_4 and cuts the mass longitudinally. The position of the Hodges Complex (along Cameron's Line), and its relation to the regionally developed structural fabrics would indicate that the Hodges and Cameron's Line were folded together by F_4 rather than being intruded into the core of the flexure, as had been previously suggested (Gates and Christensen, 1965).

V - METAMORPHISM AND METAMORPHIC HISTORY

Field and petrographic data of crosscutting metamorphic fabrics indicate polyametamorphic conditions such that metamorphic recrystallization took place at different times with respect to structural fabrics. The peak of regional metamorphism in the study area reached kyanitestaurolite grade suggesting pressures in excess of 5 Kb and temperatures in the range of 575° C to 625° C or medium grade Barrovian metamorphism (Winkler, 1974).

Contrary to previous reports the Waramaug-Hartland boundary is not a sillimanite isograd, although sillimanite grade rocks do occur to the north and northwest of the study area based on reconnaissance mapping. Staurolite does not always occur in kyanite grade rocks - this has been attributed to a lack of appropriate composition rather than staurolite instability (Winkler, 1974 p.212). In psammitic and semi-psammitic rocks (Ohgr, Ohc, Ohgn, pC-Owg) representative grade metamorphic recrystallization does not appear due to the absence of primary phyllosilicates. Plagioclase is generally not twinned, making An content measurements difficult to determine optically. Plagioclase, quartz, and muscovite are omnipresent in all metasedimentary rocks except near intrusives and in amphibolites, where muscovite is rare or absent.

Metamorphic mineral assemblages recorded for the Hartland and Waramaug Formations and their sub-members are listed below in Table 2.

Table 2 - Listing of metamorphic mineral assemblages recorded for the Hartland and Waramaug Formations and their sub-members.

The Waramaug Formation (p€-Owg)

biotite-garnet-opaque-quartz-plagioclase-muscovite
biotite-garnet-opaque-chlorite-quartz-plagioclase-muscovite
biotite-garnet-opaque-kyanite-staurolite-quartz-plagioclase-muscovite
biotite-garnet-opaque-kyanite-quartz-plagioclase-muscovite

The Waramaug Formation - amphibolite and amphibolitic gneiss (p€-Owga)

hornblende-biotite-opaque-plagioclase-quartz
hornblende-biotite-opaque-garnet-plagioclase -quartz

The Hartland Formation - upper member (Ohgr, Ohgn, Ohgk)

biotite-opaque-quartz-plagioclase-muscovite
biotite-opaque-quartz-garnet-chlorite-plagioclase-muscovite
biotite-opaque-quartz-kyanite-staurolite-garnet-chlorite-plagioclase-muscovite

The Hartland Formation - lower member (€-Ohmk)

biotite-garnet-opaque-quartz-plagioclase-muscovite
biotite-garnet-opaque-kyanite-quartz-plagioclase-muscovite
biotite-garnet-opaque-kyanite-chlorite-quartz-plagioclase-muscovite
biotite-garnet-opaque-kyanite-staurolite-quartz-plagioclase-muscovite
biotite--garnet-opaque-staurolite-chlorite-quartz-plagioclase-muscovite
biotite-garnet-opaque-kyanite-staurolite-chlorite-quartz-plagioclase-muscovite

The Hartland Formation - amphibolites (combined) - (Ohau, €-Oha)

hornblende-biotite-opaque-quartz-plagioclase
hornblende-biotite-opaque-garnet-quartz-plagioclase
hornblende-biotite-opaque-epidote-quartz-plagioclase
hornblende-biotite-opaque-chlorite-quartz-plagioclase
hornblende-biotite-opaque-chlorite-epidote-quartz-plagioclase
hornblende-epidote-opaque-quartz-plagioclase
hornblende-epidote-opaque-chlorite-quartz-plagioclase

Metamorphic mineral assemblages recorded for the Hartland and Waramaug Formations in the vicinity of the Hodges Complex are most consistent with the idea that the peak of metamorphism was attained after the juxtaposition of these two major belts since late garnet, kyanite, and staurolite porphyroblasts enclose S_2 structures and minerals in both rocks. Kyanite is generally observed to grow mimetically along S_2 micaceous folia. Textural relations indicate that metamorphism was prograde until F_4 time. The peak of metamorphism was reached after the development of the regional schistosity (S_2) but before the major F_4 flexure since kyanite, staurolite, and garnet overgrow S_2 but are cut by S_4 .

Minor retrograde biotite, quartz, and chlorite are commonly observed in thin section and megascopic sample. The orientation of these minerals within S_4 suggests that the F_4 event was at a lower grade compared to the kyanite-staurolite peak throughout the study area. Water pressure which probably developed during and after peak metamorphism is the probable cause for the unusual development of cummingtonite, tremblite, actinolite, hornblende, and chlorite in ultramafic rocks of the Hodges Complex, since these minerals replace relict pyroxenes and are sometimes aligned within S_4 .

CONTACT METAMORPHISM

The most striking metamorphic effects which have been recorded in the rocks at the contact zones of the Hodges Complex are an omnipresent garnet enrichment and the elimination of muscovite. Euhedral to subhedral garnets up to 1 inch in diameter are found to enclose S_2 in thin section, and to be deformed by late folding events (F_4 , $F_5?$).

Textural changes are observed in metasedimentary rocks as one approaches the contact of the Hodges Complex. Typical metamorphic fabrics of parallel micas, and quartz and feldspar are destroyed and replaced by randomly oriented crystals of such minerals as cordierite, kyanite, staurolite, garnet, and biotite in pelitic rocks. Rocks at the contact zone are most conspicuous since they are often denser, finer grained, more garnet rich, and less well foliated than rocks outside the aureole (Figure 14).

No contact metamorphism has been observed near contacts of the Tyler Lake Granite. Rather, millimeter thick sills of granitic material intrudes into and replaces the regional structures of the country rocks.

In quartzitic terrains (Hartland Ohc), interbeds of mica granulite show evidence of post- S_2 garnet near intrusive rocks. Garnets are generally concentrated within dioritic rocks near contacts with metasediments. This relationship is attributed to alumina metasomatism during intrusion. Garnets in metasediments are generally observed within 20 feet from intrusive contacts, but in some cases have been observed up to 100 feet away.



Figure 14 – Typical garnet enrichment at contacts of the Hodges Complex and intruded metasediments. In this case, Hartland granulite (Ohgr) is hornfused at a contact with hornblende gabbro (Hg).

Amphibolites of the Hartland and Waramaug Formations (Ohau and p€-Owga) bear S_2 enclosing garnets near contacts with the Hodges Complex (H-56, H-141). One sample of amphibolite (H-30b) shows green hornblende overgrown on an F_2 fold of S_1 . Minor hypersthene has also been recognized in the same section.

At a contact of the Waramaug Formation and Hodges diorite, flow layering parallels the regional schistosity (S_2). Directly at the contact in thin section, post- S_2 porphyroblasts of garnet and plagioclase has been noted (H-43).

Where gabbroic rocks intrude calc-silicates, quartzites, and schistose interbeds of the Hartland Ohc member, a colorless amphibole of the cummingtonite-grunerite series (actually closer to grunerite) is found. Contact recrystallization occurred under static conditions as amphiboles are in random orientation (H-116). Away from intrusives Hartland Ohc rocks are mica quartzites with minor plagioclase.

To the northeast of Klug Hill, gabbroic rocks intrude into the Hartland granulite member (Ohgr). An assemblage of cordierite-kyanite-staurolite-plagioclase (An_{23})-garnet-biotite-quartz-magnesium chlorite is found at the contact (H-169). The hornfels contains cordierite with typical pinnite alteration (Figure 15), uniaxial -, with some suggestion of complex twinning. Cordierite was confirmed by thin section, selective staining (after Boone and Wheeler, 1968), and x-ray diffraction. Garnets from the same sample (H-169) are atypical for the study area, exhibiting a pink to purple color.



Figure 15 – Cordierite (CORD) with typical pinnite (Pi) alteration and crystals of kyanite (KY). Specimen (H-169) is from within 5 feet of the contact with Hodges gabbro and Hartland granulite (Ohgr). Field of view of photomicrograph is 1 millimeter.

Where ultramafic rocks intrude into the Hartland Formation (Ohgr, and Ohc) on the hill to the SW of the intersection of Route 4 and Weed Road, garnets contain small microlites of sillimanite. Both garnets and staurolite at the contact are crystallized across oriented S₂ opaques (H-69).

Since contact mineralization poikiloblastically encloses S₂, the Hodges Complex clearly was intruded following or nearly synchronous with the formation of the regional schistosity. In addition, the intrusive contact and hornfelsing of rocks on both sides of Cameron's Line suggest that the Hodges pluton was intruded into Cameron's Line after its development.

Table 3 shows the contact assemblages in the country rocks near the Hodges Complex compared with the regional assemblages outside the contact aureole.

Table 3 – Contact assemblages in country rocks near the Hodges Complex compared with the regional assemblage outside the aureole.

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 ft from contact.
H-31	Ohgk	cord-ky-st-bi-qtz	musc-bi-qtz-plag-ky±st	Contact of gabbroic and ultramafic rocks with a screen of Hartland rocks from the SW intersection of Weed Road and Route 4.
H-68	Ohc	st-gt-qtz-bi-sill	qtz-musc-plag	
H-69	Ohgk	cord-ky-gt-st-sill-bi-qtz-chl	musc-bi-qtz-plag-ky+st	
H-30b	Ohau	hyp-hb-plag-bi-op	hb-plag-bi-op	
H-43	pC-Owg	gt-plag-qtz-bi	gt-plag-qtz-bi	From contact of Waramaug and diorite NNW of the Hodges Complex
H-52A	pC-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	pC-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 ultramafic rocks N of the Hodges Nickel Prospect

Key:

cord - cordierite
 plag - plagioclase
 hb - hornblende
 ky- kyanite
 qtz - quartz
 op – opaque minerals
 st – staurolite

chl - chlorite
 grun - grunerite
 gt - garnet
 sill - sillimanite
 bi - biotite
 hyp - hypersthene

POSSIBLE TEMPERATURE AND PRESSURE DURING INTRUSION

The mineral assemblages cordierite -garnet is unique to the contact aureole of the Hodges and is found nowhere else. In addition, kyanite and cordierite co-exist with garnet-staurolite-quartz-plagioclase and biotite (H-169). There is a marked absence of muscovite and potassium feldspar in these contact rocks.

Kyanite-cordierite coexistence is not commonly reported in the geological literature, although recent laboratory evidence indicates that there is significant overlap in the stability fields of kyanite and cordierite-garnet (Hensen and Green, 1973).

The disappearance of muscovite and absence of sillimanite and K⁺ bearing phase is a problem since muscovite is stable at temperatures up to 700° C at pressures near the Al₂SiO₅ triple point. It is possible that muscovite was eliminated by reaction 3 in Figure 16 (curve plotted is for oligoclase composition of plagioclase). There is abundant evidence for the presence of kyanite and for the evolution of granitic liquids as pegmatites throughout the study area (removing K⁺). The elimination of muscovite could also have taken place via reaction 2, although the presence of kyanite and absence of sillimanite (except for a singular, minor occurrence) would argue against such a paragenesis.

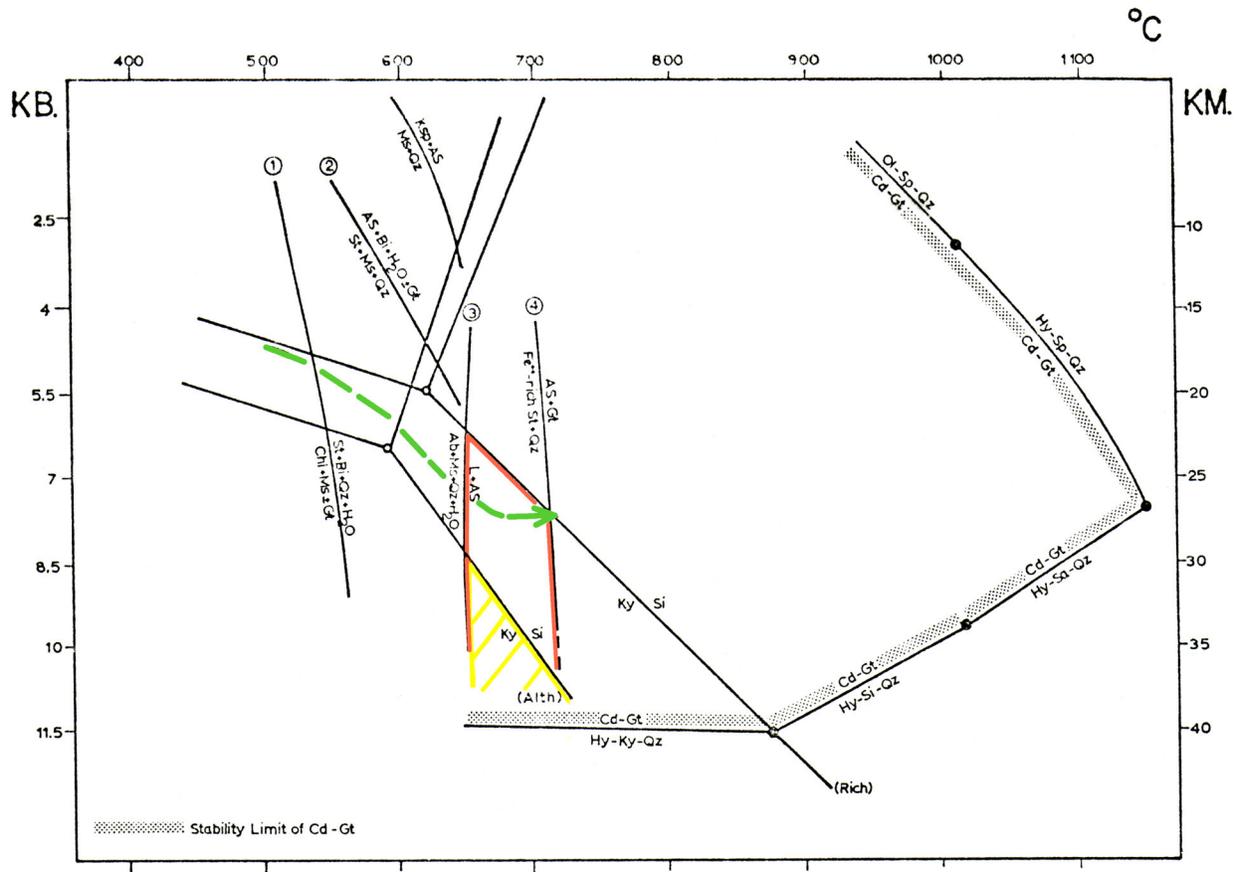


Figure 16 – The bold arrow is the suggested P-T trajectory experienced by rocks in the West Torrington quadrangle. Abbreviations used are albite (Ab), aluminosilicate (AS), biotite (Bi), chlorite (Chl), cordierite (Cd), garnet (Gt), hypersthene (Hy), potassium feldspar (Ksp), kyanite (Ky), granitic liquid (L), muscovite (Ms), olivine (Ol), quartz (Qz), sapphirine (Sa), sillimanite (Si), spinel (Sp), and staurolite (St). From Hensen and Green (1973), Storre and Karotke (1971), and Winkler (1974). Triple points of: (Alth) = Althaus (1967, 1969) and (Rich) = Richardson et al., (1968, 1969).

The equilibrium contact assemblages listed on Table 3 would suggest a P-T area of intrusion as shown between curves 3 and 4 in red and yellow on Figure 16 (however, equilibrium has not been proven between all minerals listed in a particular contact specimen!). If Althaus' estimate of the location of the aluminosilicate triple point is more nearly correct, then the P-T conditions of the Hodges intrusion would be defined by the yellow ruled area only.

Therefore the range of possibilities for prevailing P-T conditions during intrusion of the Hodges Complex vary from about 23 to 40 km of depth (6 to 11 Kb pressure) and temperatures ranging from 675° C to 700° C. Certainly the extremely high pressures are unreasonable since there is no evidence of eclogite in the ultramafic and mafic areas, nor of pyroxene or hornblende granulite mineralogy in the schistose country rocks. In actuality hornfelsic rocks do not differ markedly in mineralogy or texture from "normal" schists, gneisses, and amphibolites.

In the country rocks, post-S₂ staurolite-kyanite-garnet-biotite assemblages have been noted, and sillimanite grade rocks appear to the north and northwest of the study area. Because the contact aureole and regionally metamorphosed rocks outside the aureole contain staurolite, kyanite, garnet, and biotite porphyroblasts that include the regional schistosity (S₂), intrusion and post - S₂ regional metamorphism may have occurred at the same crustal levels. Because there is no clear overprinting of contact minerals by the late, post-S₂ regional metamorphism, the simplest interpretation is that the contact metamorphism and intrusion, and peak of regional metamorphism were coeval. These relationships suggest that intrusion of the mafic-ultramafic rocks was an Acadian event because kyanite+staurolite rocks of Silurian and Devonian age crop out nearby.

These assumptions would argue for an extreme limitation of suggested pressures of intrusion to just below the Al_2SiO_5 triple point or pressures between 6 to 8 Kb. In addition, it would appear that the Richardson et al. (1968, 1969) estimate of the location of the triple point is more applicable here.

If this is true, prograde metamorphism probably followed a trajectory as shown on Figure 16 as a bold arrow. The flattening of the metamorphic trajectory arrow just below the triple point records local temperature increase at the walls of the Hodges Complex.

VI - SUMMARY OF CONCLUSIONS

STRATIGRAPHIC CONCLUSIONS

Metamorphic rocks of the Hartland Formation in the West Torrington quadrangle are correlative with the Pinney Hollow-Chester-Ottaquechee-Stowe-Moretown sequence of east central Vermont and their extensions into Western Massachusetts. Mapping of Hartland sub-members and regional correlation would suggest a revision of Gates' Hartland I, and II, and elimination of unit III in the present study area. Stratigraphic relations of Hartland rocks would indicate the presence of an inverted sequence in the West Torrington quadrangle.

STRUCTURAL CONCLUSIONS

Four, and possibly five periods of folding have been recognized in rocks adjacent to the Hodges Complex:

F₁ and F₂ - Isoclinal folds

F₃ - syn-intrusive folds due to the Hodges Complex and the Tyler Lake Granite

F₄ - SW plunging, dextral, overturned synformal folds, and,

F₅? - warp of the S₄ axial surface.

Cameron's Line is recognized as a zone of structural discordance characterized by shearing, F₂ isoclinal folding, transposition of S₁ structures, and map scale truncation of Hartland sub-members.

The strike of the regional schistosity (S₂) is parallel to the trace of Cameron's Line, and their formation is believed synchronous.

CONCLUSIONS CONCERNING THE HODGES COMPLEX

Field mapping and structural analysis indicates that the Hodges Complex is a small, mushroom-shaped pod of pyroxenite, hornblendite, gabbro and diorite in which ultramafic rocks crosscut a central core of hornblende gabbro with a dioritic chilled margin.

The Hodges Complex is younger and not genetically related to polydeformed Hartland amphibolites to the south as suggested by Gates and Christensen, (1965). Both the Hodges Complex and the Tyler Lake Granite were deformed by F₄, and they may have been the pivot point of this fold, acting as immobile plugs.

METAMORPHIC CONCLUSIONS

Prograde Barrovian dynemothermal metamorphism was continuous until F₄ time. Staurolite-, kyanite-, and garnet porphyroblasts related to the peak of regional metamorphism enclose the regional schistosity (S₂) suggesting that the metamorphic peak occurred after the formation of Cameron's Line.

Contact metamorphism adjacent to the Hodges Complex is characterized by the elimination of muscovite and the growth of cordierite, kyanite, staurolite, garnet, and biotite. These minerals also show evidence of forming after the regional schistosity (S₂). It is suggested that the regional peak and the intrusion of the Hodges Complex were synchronous and occurred at the same crustal levels. During intrusion local pressures in the range of 6 - 8 Kb and temperatures in the range of 675°C - 700°C have been estimated.

Because the Hodges Complex is intruded across and has induced a static contact metamorphism on the fault-related fabric of Cameron's Line, it is unlikely that this mafic-ultramafic mass is ophiolitic, despite its occurrence at what may be a major tectonic boundary.

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PLATES

Note: Plates 1 and 2 are large format maps (1:12:000 scale) that would not scan easily. Copies are on file at the science library of The City College of New York, Convent Avenue and 138th Street, NYC, NY 10031 or available from Interlibrary loan programs. High resolution scans are also available at www.Dukelabs.com. Some plates are reproduced in reduced scale below.

EXPLANATION TO PLATE I

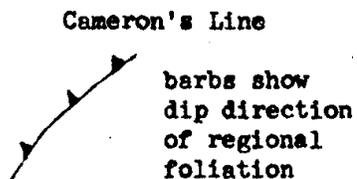
Igneous and meta-igneous rocks

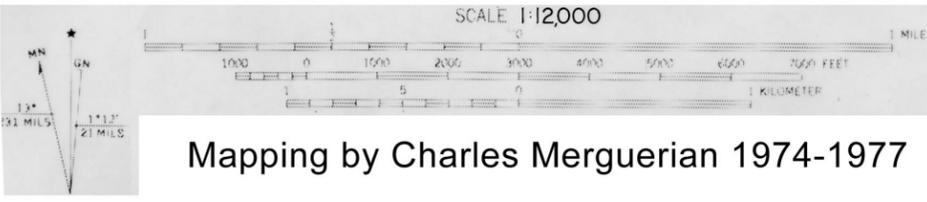
G _i	Granitic rocks
M _i	Intermediate to Mafic rocks
U _i	Ultramafic rocks

Sedimentary and Metamorphic rocks

M	Mesozoic rocks
S-D	Silurian and Devonian rocks
Oh	Hawley Formation and correlatives
Oma	Manhattan Formation undivided
Om	Moretown Formation and correlative rocks
OEG	Stockbridge, Inwood and Woodville carbonate rocks
OE	Hartland Formation undivided
HT	Hartland Formation divided. Units I, II, III, IV and their amphibolites
OGr	Rowe Schist and correlative rocks
Wg	Waramaug Formation
Ch	Hoosac Formation
Fgn	Fordham Gneiss
pC	Gneisses of the Hudson, New Milford, Housatonic and Berkshire Massifs

SYMBOLS



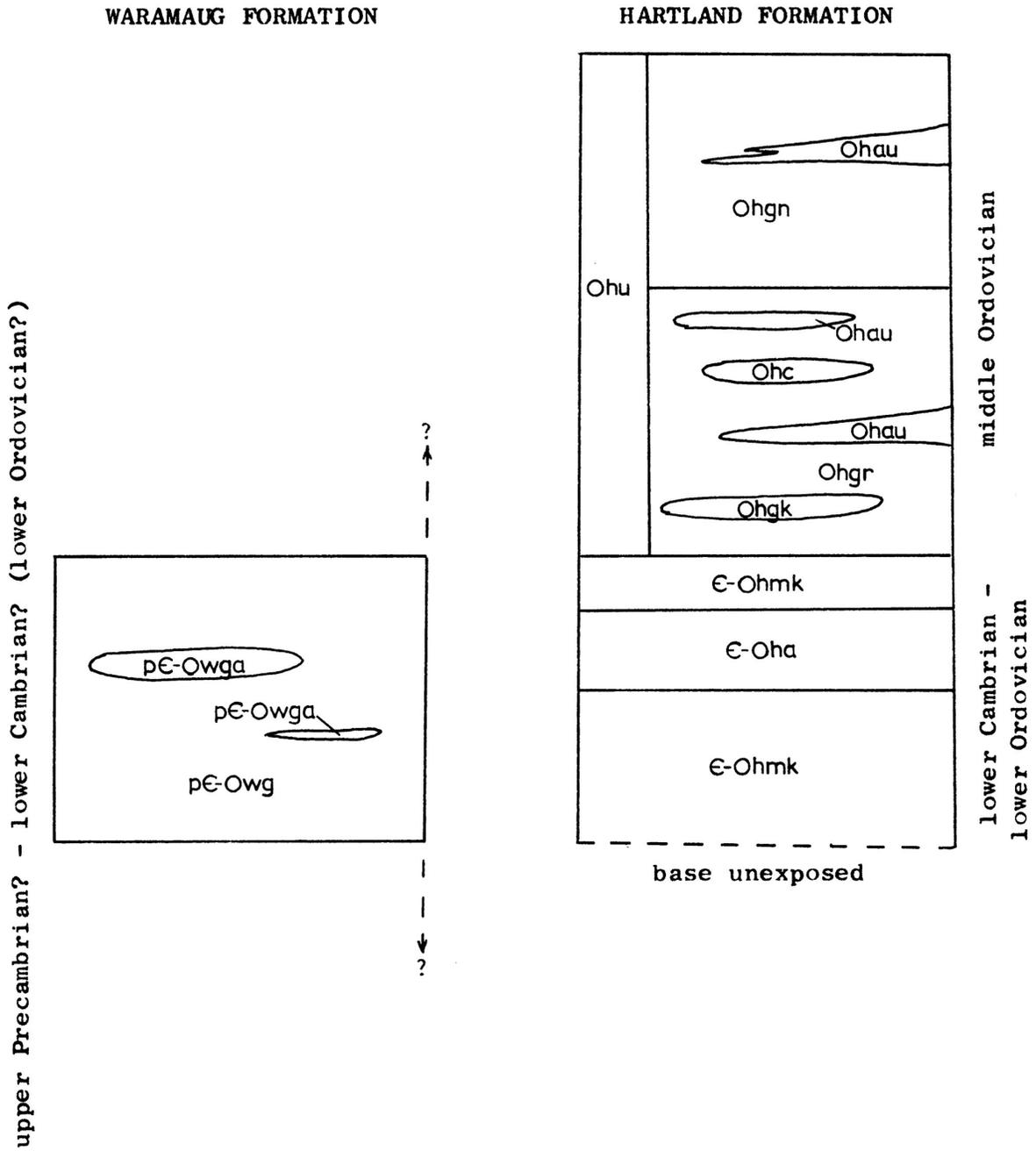


Mapping by Charles Merguerian 1974-1977

PLATE 2 - Geological Map of a Portion of the West Torrington quadrangle, Connecticut

Note: Full resolution versions of this map in 300 dpi and 600 dpi can be downloaded from www.Dukelabs.com in .pdf format. Lines of geological sections (Plate 4, below) shown on map above.

STRATIGRAPHIC COLUMN



EXPLANATION

META-IGNEOUS ROCKS

Minerals are listed in order of decreasing abundance. Those in parentheses are not found in all exposures.

P

Pegmatites - Medium to coarse grained, gray weathering to iron-stained, chalk white, pinkish white to orange white, albite-microcline-quartz-muscovite-biotite pegmatite and granite with accessory (biotite)-(tourmaline)-(ilmenite)-(beryl)-and (garnet). Best developed near and west of the Tyler Lake Granite, areas of closely spaced pegmatite in pods $\frac{1}{2}$ inch to 50 feet in thickness are shown by a special symbol . Contact relations are both concordant and discordant with respect to the regional schistosity or gneissosity (S_2) with most pegmatites exhibiting a faint shear or micaceous foliation as an S_4 fabric.

Tg

Tyler Lake Granite - Fine grained to pegmatitic, well foliated, gray weathering, quartz-microcline-plagioclase-muscovite-biotite-(garnet)-(chlorite) granite that shows evidence of metamorphic recrystallization in the form of aligned micas. In some instances the Tyler Lake Granite appears rhythmically layered with more finer grained and foliated granite which is more typical of the mass. The Tyler Lake Granite includes xenoliths of regionally foliated schist and appears to be syn-tectonic with respect to F_3 folds.

THE HODGES COMPLEX

Intrusive into the Waramaug and Hartland Formations

P_D

Meta pyroxenite-hornblendite - Highly altered, medium grained to pegmatitic, dense, deeply iron-stained, silver-green to dark green to black rocks consisting of varying proportions of olivine-hypersthene-enstatite-augite-hornblende-cumingtonite-tremolite-actinolite-anthophyllite-biotite-chlorite-(plagioclase)-(epidote)-(magnetite)-(ilmenite)-(zircon)-(apatite)-(sphene)-(talc)-(serpentine). Types noted are Hornblende orthopyroxenites, Biotite-Tremolite-orthopyroxenites, Orthopyroxene hornblendites, Hornblendites, Biotite hornblendites, Hornblende gabbros, Hornblende diorites, Porphyritic hornblende diorites, and serpentinites. Detailed descriptions of igneous and metamorphic textures and mineralogy are within the text. Rocks are broken with great difficulty and tend to break along pre-existing iron-stained cracks that are not immediately visible on the weathered surface. Outcrops are rounded and show evidence of spheroidal weathering. Much ultramafic float is observed southeast of the Hodges Complex.

early Devonian - middle Devonian (?)

early Devonian (?)

Di

Meta-diorite - Medium to very coarse grained, dark to light gray weathering, iron-stained, gray-green to black and white banded hornblende-plagioclase-biotite-opaque-(quartz)-(epidote)-(sphene)-(apatite)-(garnet) diorite that has a layered aspect composed of sub-parallel, subhedral to euhedral hornblende and plagioclase. This layering is interpreted as flow layering. Garnets occur as large euhedral crystals (often deformed) up to 100 feet away from contacts with intruded metasediments. Flow layering is generally parallel to the regional schistosity (S_2) of the enclosed metasediments but in some instances diorite flow layering truncates these structures. Late anastomosing dikes of identical mineralogy are most common.

Hg

Meta-gabbro - Medium to very coarse grained, dark gray weathering, iron-stained, speckled, gray-green to black and gray-white, hornblende-plagioclase-biotite-opaque-(quartz)-(sphene)-(apatite)-(chlorite)-(zircon) gabbro that shows evidence of post-magmatic recrystallization. Labradorite (An_{50-55}) is less abundant than or equal to hornblende with both of these minerals comprising about 90% of the total rock volume. Textures vary from blotchy, obviously recrystallized areas of hornblende and plagioclase, to facies where euhedral crystals of hornblende are in a granular plagioclase matrix. Flow layering is generally only measureable at or near contacts with older rocks. Outcrops are generally massive but can be broken with little difficulty. Minor areas of pegmatitic hornblende gabbro are present. Areas of poikilitic hornblende gabbro or diorite with large plates of hornblende up to $\frac{1}{2}$ inch in diameter exhibiting a porphyritic texture are only recognized in gabbroic and ultramafic areas.

METAMORPHIC ROCKS

Ohu

Hartland Formation (upper member) - Gneiss, granulite, amphibolite, schist member. Occurring as a continuous belt through the Hodges Complex, with great variation in thickness from 600 feet to 2300 feet between the Waramaug Formation and the lower member of the Hartland Formation, the upper member can be divided into the following sub-members:

Ohgn

Gneiss member - A lustrous, typically non-rusty weathering, gray, quartz-plagioclase-muscovite-biotite-(graphite) gneiss and minor schist often with crumbly feldspathic interlayers up to 6 inches thick. Alternating quartzofeldspathic bands and thin micaceous folia impart a pin-striped appearance in some areas while in others, smoky-gray quartz layers up to 2 inches thick and dark quartz layers are present. There is a scarcity of aluminosilicate minerals in these rocks.

Ohau

Amphibolite member - Fine to medium grained, rusty and non-rusty weathering, gray-green or whitish on weathered surfaces, dark-green to green-black hornblende-plagioclase-biotite-(quartz)-(epidote)-(chlorite)-(ilmenite)-(pyrite) amphibolite. Amphibolites within the Hartland Formation upper member are typically dense, dark green rocks composed of prismatic hornblendes aligned within the regional schistosity. Alternating bands of plagioclase and minor clear, recrystallized quartz separate hornblende rich laminations. In comparison to amphibolites of the Hartland lower member, these rocks show less diversity in mineralogy and tend to be epidote poor.

Ohgr

Granulite member - A slabby, well bedded, faint to strongly brown weathering, quartzofeldspathic granulitic gneiss or granulite with mica. Minor interlayers of muscovite-plagioclase-quartz-biotite schist are also present.

Ohau

Amphibolite member - Identical to rocks described above (Ohau).

Ohc

Quartzite, coticule, calc-silicate member - Mica quartzite, quartz-garnet granulite, and calc-silicate rocks that are well bedded and generally separated by thin, continuous micaceous layers $\frac{1}{4}$ inch to 3 feet in thickness. Mica quartzites are punky weathering, well laminated and vitreous with tan muscovite on fresh surfaces. Coticule rock is rusty to gray weathering, compact and well bedded with alternating bands of metallic gray, bluish-gray, tan and whitish and disseminated garnet. Calc-silicate rock is green to brown-green in color, non-rusty weathering with an outward appearance not unlike that of amphibolitic rocks mentioned above. All of these types are fine grained except for some mica quartzites. They occur within the granulite member (Ohgr) and are surrounded by a distinctive purple-gray quartz-biotite-plagioclase granulite and granulitic gneiss.

Ohau

Amphibolite member - Identical to rocks described above (Ohau).

Ohgk

Kyanite schist member - A fine to medium grained, locally rusty weathering quartz-plagioclase-muscovite-biotite-kyanite-garnet schist and schistose gneiss that, when present, invariably occurs near the Hartland Formation lower member contact as discontinuous layers or lenses.

E-Ohl

Hartland Formation (lower member) - Muscovite-kyanite schist and amphibolite member. Occurs as a 1000 foot thick sequence in the study area and can be divided into the following sub-members:

E-Ohmk

Muscovite-kyanite schist member - A highly lustrous, phyllitic to schistose, gray weathering, medium to coarse grained, quartz-muscovite-plagioclase-biotite-opaque-garnet-(ilmenite)-(kyanite)-(staurolite)-(apatite)-(chlorite) schist that often contains mega-porphyroblasts of kyanite, staurolite, garnet, and more rarely plagioclase and biotite giving the rock a knotted appearance. Fresh surfaces reveal a mirror-like finish of intergrown quartz and muscovite. Quartz and muscovite are roughly equivalent in proportion and together comprise more than half of the rock volumetrically. Rocks generally part with little difficulty along the regional schistosity and in the presence of planar slip cleavages will often break into slender, feet long splintery masses that have been used as fence-posts in the past. Granular, clear to smoky gray quartz pods are most conspicuous and generally found elongate within the regional schistosity. The lower member becomes markedly hornblende, chlorite, and/or biotite rich near contacts with its inter-layered amphibolite member and often these minerals are incorporated into elliptical quartz pods. Some zones are non-porphyroblastic while others more typically contain spongy 3 inch staurolite and 4 inch kyanites in random post-regional schistosity growth. Minor discontinuous interlayers of a hornblende-chlorite quartz granulite are present near the lower member schist amphibolite contact. With an increase in plagioclase content and a decrease in micaceous minerals, the lower member grades, with some lensing, into the upper member.

E-Oha

Amphibolite member - Fine to medium grained, rusty and non-rusty weathering, gray-green or whitish on weathered surfaces, lime-green through dark green to green-black hornblende-plagioclase-biotite-(quartz)-(epidote)-(chlorite)-(opaque)-(ilmenite)-(garnet)-(thulite) amphibolite. Amphibolites consist of interlayered and laterally variable lithologies characterized by one of the four lithic types listed below. Contacts are gradational.

1. a tri-colored, pin-striped amphibolite with foliation planes of white or yellow-white, light green and dark green, all intimately alternating to compose a dense but easily parted rock.
2. a light green to yellow-green epidote rich amphibolite with a layered appearance due to compositional variations. Epidote is locally up to 50% of the total rock volume. Individual layers are up to 6 inches thick.
3. a dense, iron-stained, dark green rock composed of felty, prismatic, lieated hornblendes aligned within the regional schistosity. Some zones weather into a crumbly mass of hornblendes but retain their green color. Alternating bands of plagioclase and minor clear, recrystallized quartz also define the regional schistosity.
4. a well bedded, green, pink and tan, actinolite-plagioclase-quartz granulitic amphibolite with interpenetrant, radiating laths of actinolite set in a quartzofeldspathic fine grained matrix.

Waramaug Formation - A heterogeneous assemblage of brown and gray weathering, poorly foliated and generally indistinctly bedded gneisses with minor schists and amphibolites. Two types have been noted although their stratigraphy and structure is not understood at present:

pEOWg

- a granular quartz-biotite-plagioclase-muscovite-garnet-opaque gneiss which can be distinguished by its light gray color on fresh surfaces and often the presence of zoned plagioclase porphyroblasts within the gneissosity.
- a quartz-plagioclase-biotite-garnet-muscovite-opaque-(kyanite)-(staurolite)-(chlorite)-(tourmaline) gneiss and minor schist which can be distinguished by its nubby surface and spindly appearance due to differentially weathered aluminosilicate minerals.

Zones of non-mapable extent include gray quartzite interlayers varying from 1 inch to 3 inches thick, biotite-quartz-plagioclase schist, quartz-plagioclase-muscovite-biotite schist, tremolite-quartz-calcite granulite (special symbol - trem. X). Some zones are sulphitic consisting of yellow stained, rust colored, friable rocks with a sulphur odor. Maroon weathering is also locally present. Granulites, lithically identical to Hartland upper member types are locally present. The Waramaug is most granular and biotitic at or near Precambrian contacts while in facies away from the Precambrian rocks, a heterogeneous admixture of the previously mentioned types co-exist.

At present no detailed stratigraphy has been traced for the Waramaug Formation.

Lower Ordovician (?)

upper Precambrian - lower Cambrian (?)

Precambrian

pC-Owga

Amphibolite and amphibolitic gneiss - Fine grained, gray to steel gray weathering hornblende-plagioclase-biotite-opaque-(garnet) amphibolite occurs as continuous and discontinuous streaks, lenses and layers from inches up to 100 feet thick (although higher values may be due to repetition by folding). The amphibolites lack the great variety of the Hartland types and are less well developed in comparison. Those occurring are typically gray-black to gray-green with plagioclase and minor quartz comprising laminae (where observable). These minerals vary from less than 5%, up to 20% of the total rock volume. In other places amphibolite appears devoid of felsic material in outcrop and is a dense, compact rock that is broken with difficulty. Amphibolitic gneiss often represents a transition from pelitic rock to amphibolite. A complete transition from mica gneiss through amphibolitic gneiss (occurring within 10 feet) gives way to amphibolite in its more typically massive character. In other places amphibolite contacts are sharp.

pC

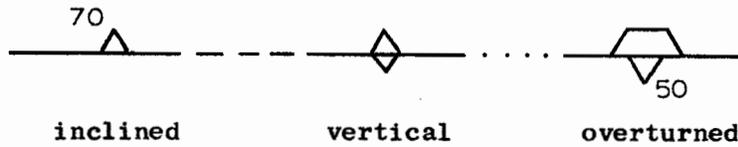
Precambrian - Undivided and unmapped in the present study. Surface distribution from Gates and Christensen, 1965.

SYMBOLS



CONTACT

Dashed where approximately located



inclined

vertical

overturned

THRUST FAULT (Cameron's Line)

Dashed where approximately located

Dotted where traced through igneous rocks

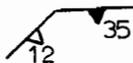


FAULT

Dashed where approximately located
 U=upthrown side, D=downthrown side
 Barb shows dip direction and angle of dip

PLANAR FEATURES

Symbols may be combined with coexisting features
 The point of intersection denotes the point of observation



- S₀ - Strike and dip of bedding shown by quartzite interbeds
- S₁ - Strike and dip of early schistosity or gneissosity and parallel compositional banding in gneisses and in amphibolites
- S₂ - Strike and dip of regional schistosity, locally with parallel compositional banding
- S₃ - Strike and dip of crenulation cleavage or slip cleavage or spaced foliation
- S₄ - Strike and dip of late crenulation cleavage or slip cleavage or spaced foliation
- Strike and dip of igneous flow layering
- Strike and dip of axial surfaces of F₁ folds
- Strike and dip of axial surfaces of F₂ folds
- Strike and dip of axial surfaces of F₃ folds
- Strike and dip of axial surfaces of F₄ folds

LINEAR FEATURES

Drag sense of minor folds as viewed in profile down the plunge
 Generation indicated by proper fold axis symbol

- left-handed
- assymetric
- right-handed

- Bearing and plunge of F₁ fold axis
- Bearing and plunge of F₂ fold axis
- Bearing and plunge of F₃ fold axis
- Bearing and plunge of F₄ fold axis

- 56  Bearing and plunge of L₁ lineation - quartz ribbing, hornblende lineation or streaking in amphibolites, mineral lineation in igneous terrains
- 56  Bearing and plunge of L₂ lineation - streaking of S₂ on S₁ in gneisses and schists, hornblende lineation or streaking in amphibolites
- 56  Bearing and plunge of L₃ lineation - trace of S₃ on the regional schistosity (S₂) (Some data plotted was calculated from oriented samples)
- 56  Bearing and plunge of L₄ lineation - trace of S₄ on the regional schistosity (S₂) (Some data plotted was calculated from oriented samples)



Abandoned Mine or Quarry

p=pegmatite
gr=gravel
g=granite

Cu=copper
s=soapstone
Ni=nickel



Well Data

Plate 3 - Axial Surface Traces

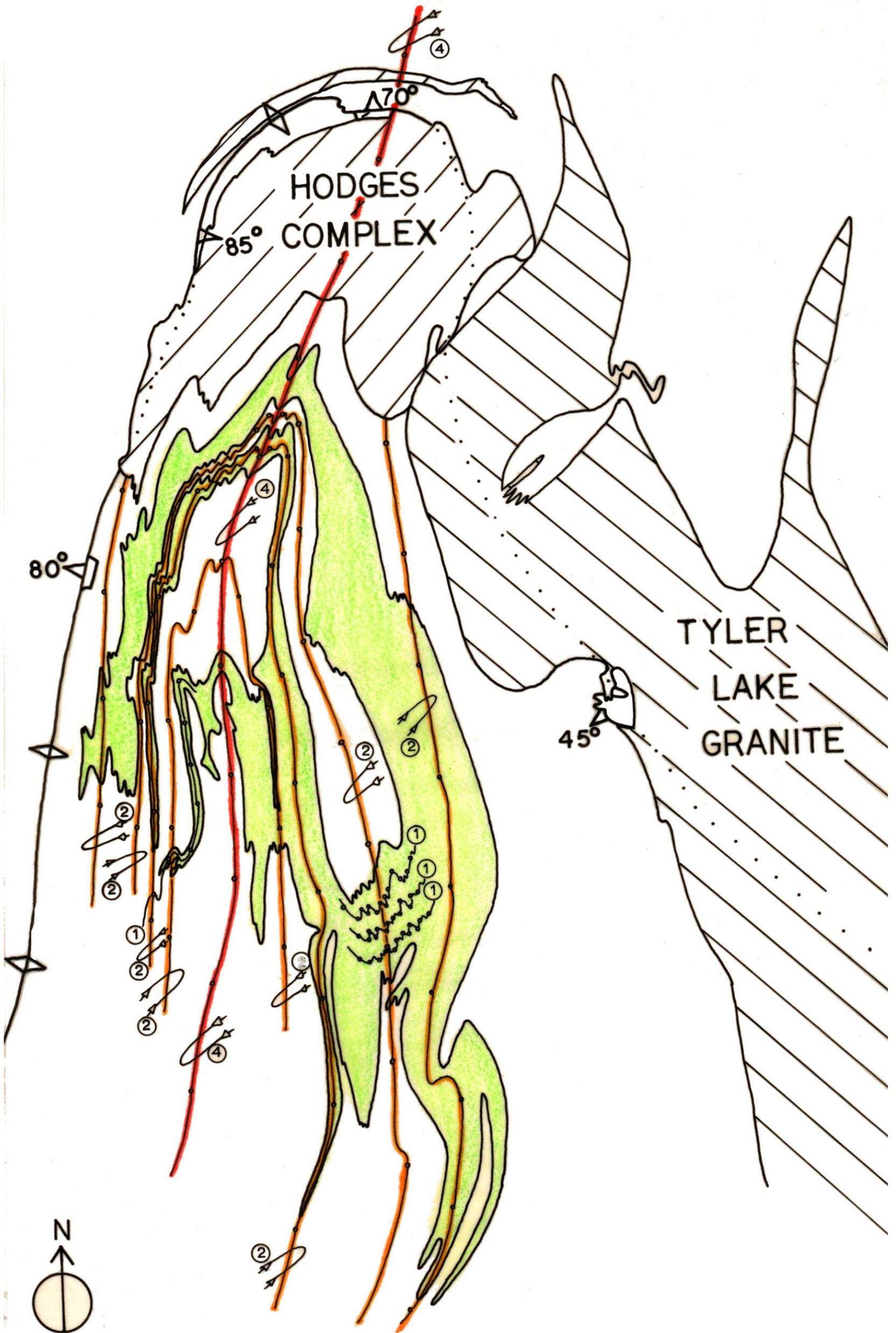


Plate 4 – Geological Sections

