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Multiple Folding in Western Connecticut: a Reinterpretation of Structure in the New Haven-Naugatuck-Westport Area

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MULTIPLE FOLDING IN WESTERN CONNECTICUT: A REINTERPRETATION OF STRUCTURE IN THE NEW HAVEN-NAUGATUCK-WESTPORT AREA

by

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INTRODUCTION

The Paleozoic metamorphic rocks of the New Haven-Naugatuck-Westport area consist predominately of metasediments with lesser amounts of metaigneous (volcanic?) rock. Gates and Rodgers (Rodgers and others, 1959) have referred to this area as "the southeastern belt" (of the Western Connecticut Highlands), a designation that is retained here. This area is to the south and east of the region of Western Connecticut gneiss domes (the "central belt") and in contrast with the irregular structure of that area, the rocks of the southeastern belt have a strongly linear northeast-trending structural pattern. The metamorphism varies from chlorite-grade in the east to sillimanite-grade in the west.

The authors of recent studies (see figure 1) have proposed a number of often conflicting interpretations of the large-scale structure of portions of the southeastern belt. All these interpretations suggest a relatively simple structure for the southeastern belt. However, the map pattern and the minor structures indicate numerous deformational episodes and a rather complex structural configuration. A regional study of the structure has resulted in the reinterpretation outlined here. For the details on which this reinterpretation is based the reader is referred to Dieterich (1968). The main goal of the field trip is to demonstrate the existence of multiple systems of minor structures and to illustrate some features of the large-scale structure.

The State Geological and Natural History Survey of Connecticut provided financial support of the field work during all or parts of the summers of 1964, 1965, 1966, and 1967. This work is from a portion of the author's Ph.D. thesis presented to the Faculty of Yale University. I am indebted to Professor John Rodgers for his advice and encouragement.

STRATIGRAPHY

The stratigraphy illustrated in figure 2 differs from that of previous workers and is based on the author's detailed observations in the Westport quadrangle and more general observations in the remainder of the southeastern belt. The correlations of Fritts (1962, 1965a, 1965b) are followed in the eastern part of the belt in the area of the Wepawaug Schist and the Derby Hill Formation. The principal features of the re-interpretation of the area to the west are the recognition of the Fairfield Formation (name tentative) and the correlation of the Prospect

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SOUTHINGTON	FRITTS, 1963b
SOUTHBURY	SCHOLLE, 1965
NAUGATUCK	CARR, 1960
MOUNT CARMEL	FRITTS, 1963a
LONG HILL & BRIDGEPORT	CROWLEY, 1967
ANSONIA	FRITTS, 1965a
NEW HAVEN	BURGER, 1967
WESTPORT & SHERWOOD PT.	DIETERICH, 1968
MILFORD	FRITTS, 1965b

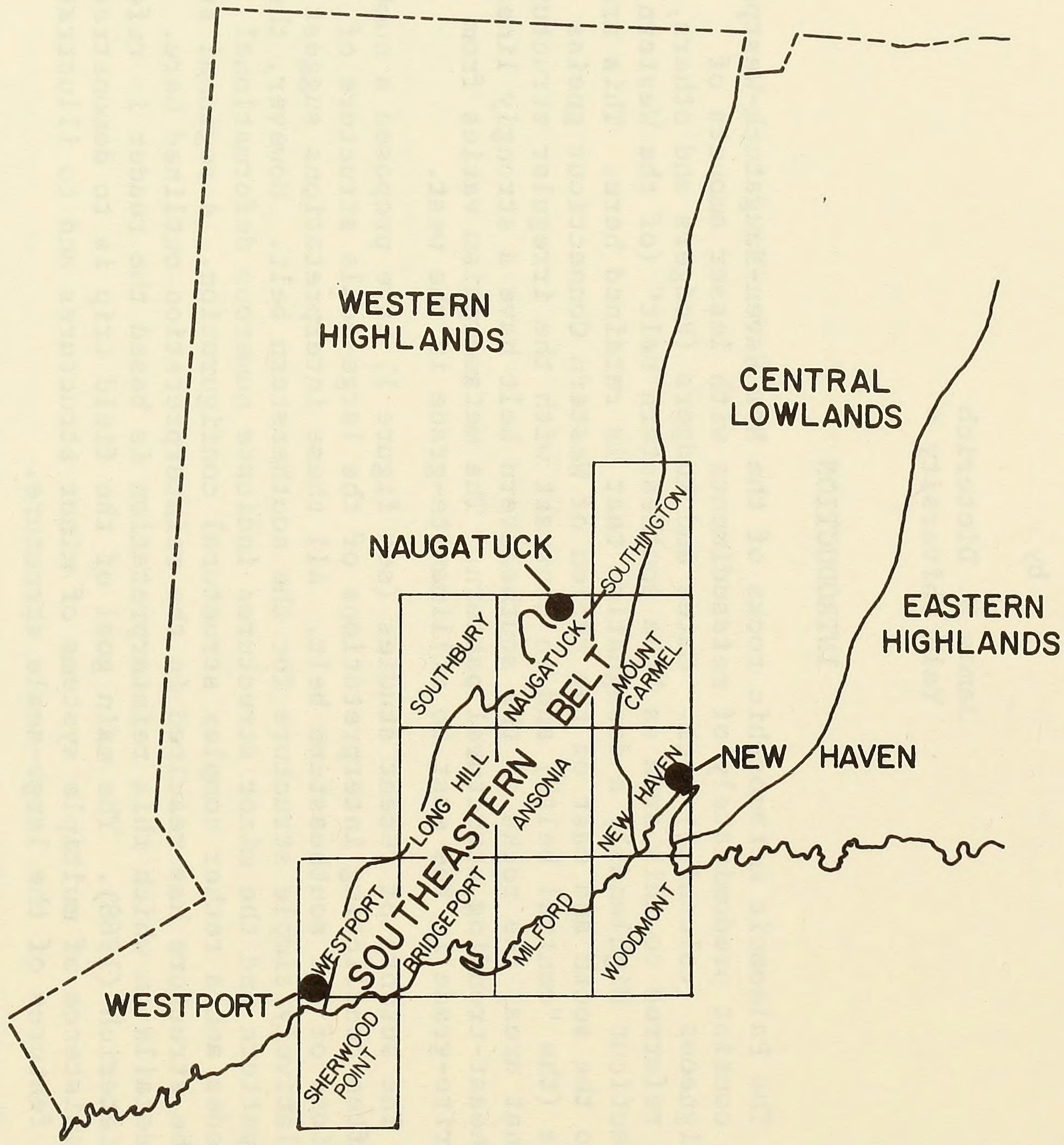

Fig. 1. Index map of the New Haven-Naugatuck-Westport area.

Formation	Member	Brief Description
Wepawaug Schist		Dark gray, graphitic phyllite or phyllitic schist (depending on metamorphic grade).
Maltby Lakes Volcanics		Mainly intermetiate to basic metavolcanic rocks with interlayered metasediments.
Allingtown Formation		Dark massive greenstone interlayered with schist. Fritts (1965a, 1965b) considered this formation to be intrusive into the Derby Hill Formation. Burger (1967), however, believes this formation to be volcanics interlayered with the upper portions of Fritts' Derby Hill Formation.
Derby Hill Formation	Oronoque Member	Thinly laminated quartz rich paragneiss. In part interlayered with the Allingtown Formation.
	Unnamed Lower Member	Thinly laminated muscovite-chlorite phyllite or schist with quartz-rich paragneiss.
The Straits Schist		A distinctive coarse quartzose muscovite schist. It is usually graphitic and often contains biotite, garnet, and sillimanite, and/or kyanite.
Fairfield Formation (name tentative)	Upper Member	Interlayered biotite-muscovite schist, biotite gneiss and quartzite with lenses of amphibolite, calc-silicates, marble, and massive quartzite.
	Lower Member	Layered muscovite-biotite schist and biotite gneiss.
Prospect Formation	Upper Member	Porphyroblastic and non-porphyroblastic gneiss, hornblende gneiss, and muscovite-biotite schist.
	Golden Hill Member	Layered muscovite-biotite schist, biotite gneiss with amphibolite, quartz-oligoclase gneiss and calc-silicates.

Fig. 2. Stratigraphy of the New Haven-Naugatuck-Westport area.

Formation with a number of other units.

To the east of the main body of The Straits Schist (see map, figure 3), the Fairfield Formation includes rocks that previously have been correlated with the Southington Mountain Formation by Fritts in the Mount Carmel, Ansonia, and Milford quadrangles (1963a, 1965a, and 1965b respectively), and rocks continuous with these in the Long Hill and Bridgeport quadrangles, variously designated by Crowley (1967) as the upper member of The Straits Schist and the Southington Mountain Formation. Along the west side of the main body of The Straits Schist, the Fairfield Formation is equated with the layered schistose and gneissose portions of the Waterbury and Prospect formations in the Naugatuck quadrangle (Carr, 1960) and portions of the Reynolds Bridge Formation in the Long Hill and Bridgeport quadrangles. North of the southeastern belt, the Fairfield Formation is correlative with the Hitchcock Lake member of the Waterbury Formation in the Waterbury quadrangle (Gates and Martin, 1967) and Southington quadrangle (Fritts, 1963b).

The above correlations are based on the occurence of a number of distinctive rock types in the upper portion of Fairfield Formation. Ocurring as lenses in interlayered biotite-plagioclase-muscovite-quartz schist, biotite gneiss and quartzite are amphibolite, marble, a number of different calc-silicate rocks and massive quartzite. Significantly, these lenses, where present, are in a well-defined sequence. At the bottom of the sequence is a thin amphibolite. Above this is a thicker zone (roughly 200 feet) of the banded schist, gneiss and quartzite which in the upper half is commonly interbedded with calc-silicate rocks. The marble occurs at or near the top of the banded schist and is followed by a massive amphibolite up to 100 feet thick. Above the amphibolite at the top of the Fairfield Formation (i.e., adjacent to The Straits Schist) is a massive quartzite up to 40 feet thick.

On the basis of the control provided by the Fairfield Formation, the Prospect Formation is correlated with similar gneisses of the Waterbury Formation in the Naugatuck quadrangle and with the Reynolds Bridge Formation and perhaps the Newtown Formation in the Long Hill quadrangle.

STRUCTURE

Minor Structures

At many exposures throughout the southeastern belt, it is possible to observe folded folds and in a few places twice-folded folds. A total of four primary minor fold systems are recognized. These are designated from oldest to youngest as F_1, F_2, F_3, and F_4, respectively. Locally along the northwest edge of the belt an additional deformational system has been found which, on the basis of the regional structure and apparent tectonic history, is interpreted as an early phase of F_2. In that part of the area the two F_2 phases are designated F_{2A} and F_{2B}. The first three of the four primary minor fold systems are associated with mappable folds.

The intensity of the deformations associated with each of these minor fold systems is quite variable. With the exception of the youngest fold system, F_4, which consists of kink-type folds, the style of the minor structures is controlled by the lithologies of the layers involved and by the local intensity of the deformations. Fold style is not determined by the fold chronology. As a result, conventional style criteria could

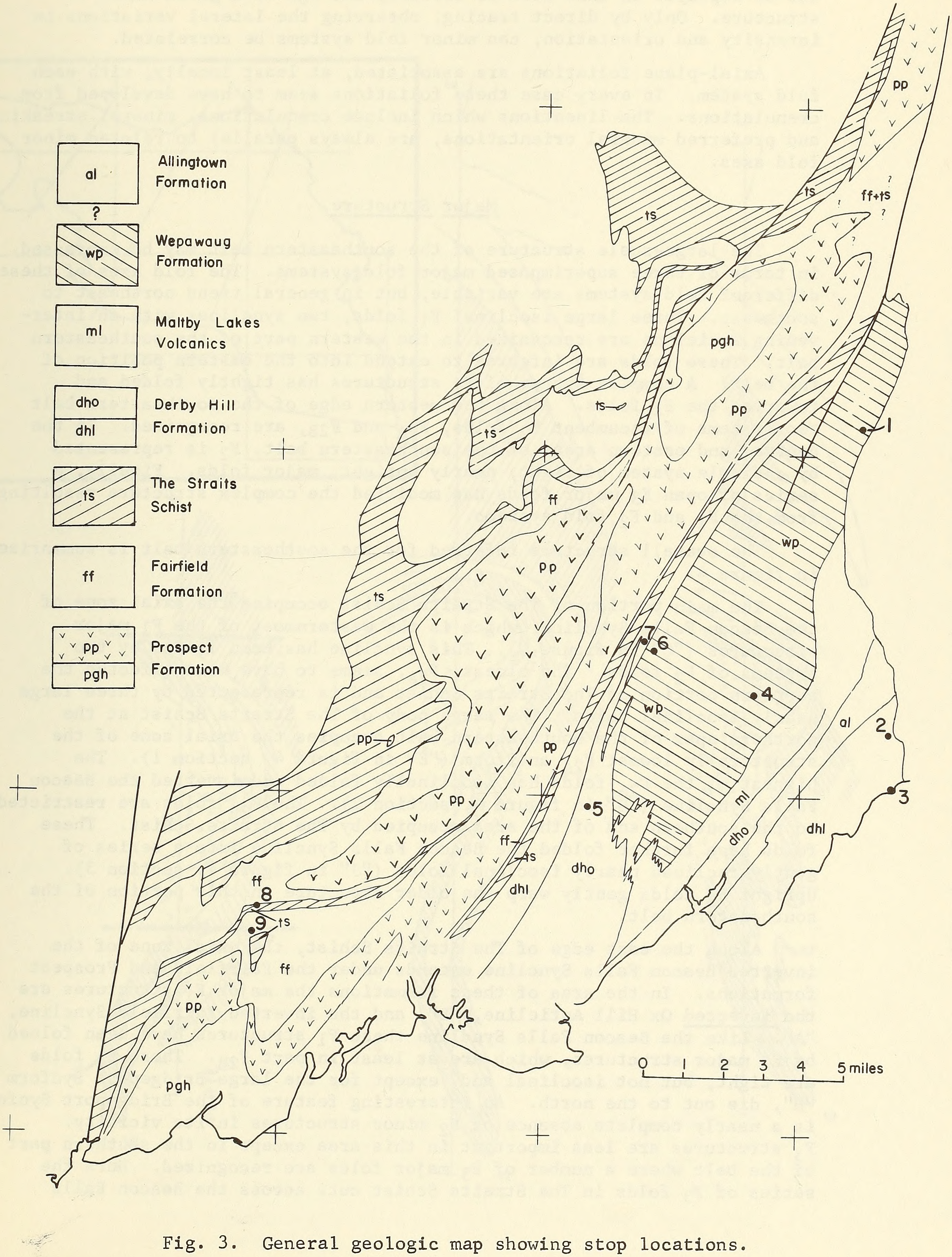

Fig. 3. General geologic map showing stop locations.

not be employed in this area to identify the age of a given minor structure. Only by direct tracing, observing the lateral variations in intensity and orientation, can minor fold systems be correlated.

Axial-plane foliations are associated, at least locally, with each fold system. In every case these foliations seem to have developed from crenulations. The lineations which include crenulations, mineral streaking and preferred mineral orientations, are always parallel to related minor fold axes.

Major Structure

The large-scale structure of the southeastern belt may be expressed in terms of three superimposed major fold systems. The fold axes of these different fold systems are variable, but in general trend northeast to southwest. Three large isoclinal F_1 folds, two synclines with an intervening anticline are recognized in the western part of the southeastern belt. These folds are inferred to extend into the eastern position of the belt. A complex system of F_2 structures has tightly folded and inverted the F_1 folds. Along the western edge of the southeastern belt two systems of recumbent F_2 folds, F_{2A} and F_{2B}, are recognized. In the central and eastern areas of the southeastern belt, F_2 is represented by a single system of tight, nearly upright, major folds. Finally, a series of open F_3 major folds has modified the complex structure resulting from the F_1 and F_2 fold systems.

The overall structure inferred for the southeastern belt is summarized in figure 4.

The main portion of The Straits Schist occupies the axial zone of the Beacon Falls Syncline, which is the westernmost of the F_1 major structures ("C" in figure 4). This syncline has been folded by two systems of F_2 folds. The oldest, F_{2A}, seems to have most affected the northern portion of The Straits Schist and is represented by three large nearly isoclinal folds. The large body of The Straits Schist at the northern apex of the southeastern belt occupies the axial zone of the structurally lowest F_{2A} antiform ("E" in figure 4, section 1). The highest of the F_{2A} folds has isoclinally folded and inverted the Beacon Falls Syncline ("G" in figure 4, section 2). The F_{2B} folds are restricted to the southern end of the area occupied by The Straits Schist. These folds have further folded the Beacon Falls Syncline into a series of gently reclined nearly isoclinal folds ("J" in figure 4, section 3). Upright F_3 folds gently warp the older structure in this portion of the southwestern belt.

Along the east edge of The Straits Schist, the axial zone of the inverted Beacon Falls Syncline extends under the Fairfield and Prospect formations. In the area of these formations the major F_1 structures are the inverted Ox Hill Anticline, "B", and the inverted Fairfield Syncline, "A". Like the Beacon Falls Syncline these F_1 structures have been folded by F_2 major structures, which are at least in part F_{2B}. These F_2 folds are tight, but not isoclinal and, except for the large Bridgeport Synform "H", die out to the north. An interesting feature of the Bridgeport Synform is a nearly complete absence of F_2 minor structures in its vicinity. F_3 structures are less important in this area except in the southern part of the belt where a number of F_3 major folds are recognized. Here the series of F_3 folds in The Straits Schist cuts across the Beacon Falls

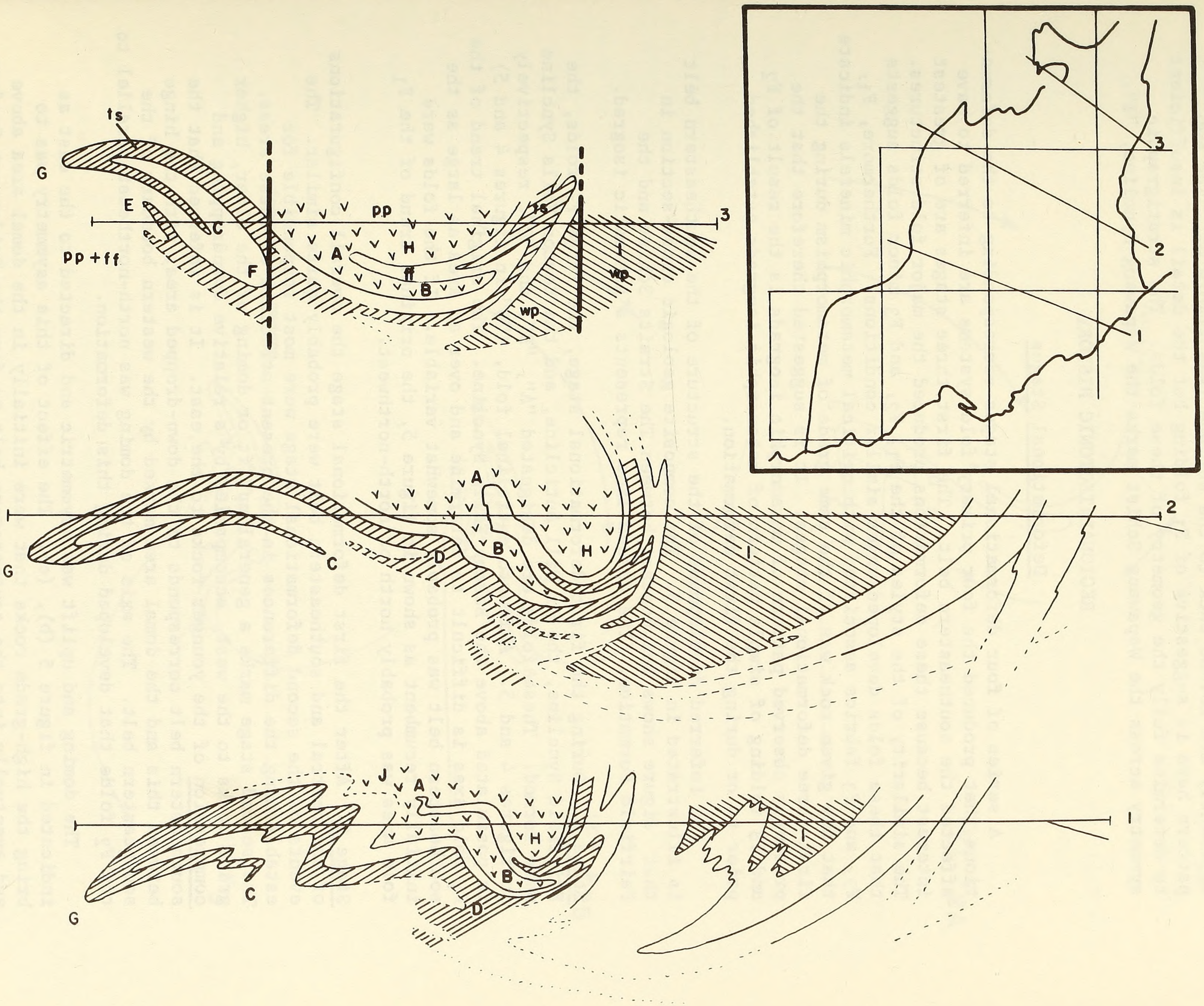

Fig. 4. Geologic cross-sections of the southeastern belt.

Syncline and folds the Ox Hill Anticline and the Fairfield Syncline.

East of the Bridgeport Synform the three inverted F_1 major folds apparently are folded back to the surface (see figure 4). The map pattern here is suggestive of F_1 folding but the detail is insufficient to determine fully the geometry of these folds. The stratigraphic symmetry across the Wepawaug Schist marks the Wepawaug Syncline, "I".

REGIONAL TECTONIC HISTORY

Deformational Stages

A series of four deformational stages corresponding to the deformations that produced the four primary fold systems are inferred to have affected the southeastern belt. The first three stages are of greatest interest because these deformations produced the major fold structures. The similarity of the styles of the F_1, F_2, and F_3 minor folds suggests that these folds developed under similar conditions. Furthermore, F_1, F_2, and F_3 fabrics associated with critical metamorphic minerals indicate that any given rock was at the same grade of metamorphism during the first three deformational stages. It is suggested therefore that the presently observed pattern of metamorphic isograds is the result of F_2 and F_3 folding of simple pattern of metamorphic isograds established prior to or during the first deformation.

The inferred development of the structure of the southeastern belt is illustrated in figure 5. The composite geologic cross-section in that figure shows the contact between The Straits Schist and the Fairfield Formation. The dashed line represents a schematic isograd.

Stage 1. During the first deformational stage, the large F_1 folds, the Fairfield Syncline, the Ox Hill Anticline, and the Beacon Falls Syncline were formed. These folds are designated "A", "B", and "C", respectively in figures 4 and 5. A fourth anticlinal fold, ("D" in figures 4 and 5) is postulated above the Beacon Falls Syncline. The original trend of the F_1 fold axes is difficult to determine and over an area as large as the southeastern belt was probably somewhat variable. If the folds were initially recumbent as shown in figure 5, the original trend of the F_1 fold axes was probably north or north-northwest.

Stage 2. After the first deformational stage the overall configurations of the central and southeastern belt were probably quite similar. The events of the second deformational stage were most responsible for establishing the differences in the present structure of these areas. The second stage marks a general uplift or doming of the older, higher grade rocks to the west, accompanied by a relative downdropping and compression of the younger rocks to the east. It is inferred that the southeastern belt corresponds to the down-dropped area, with the hinge between this and the domal area marked by the western boundary of the southeastern belt. The axis of the doming was north-northeast parallel to the F_2 folds that developed during this deformation.

The doming and uplift was asymmetric and directed to the east as indicated in figure 5 (b), (c). The effect of this asymmetry was to bring the high-grade rocks that were initially in the domal area above and eventually into the southeastern belt to form the Bridgeport Synform.

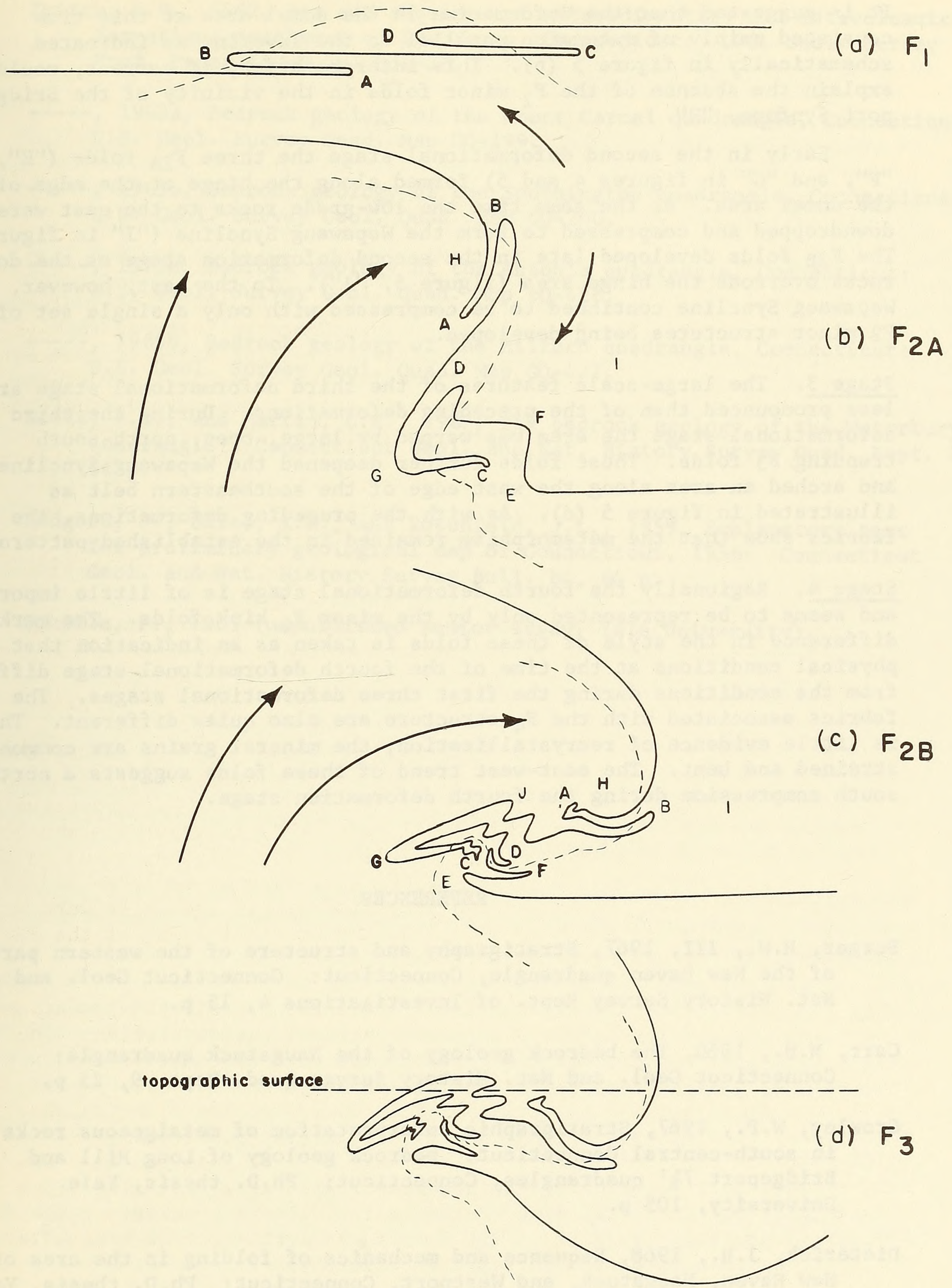

Fig. 5. Evolution of the structure of the southeastern belt. The solid line represents the contact between The Straits Schist and the Fairfield Formation. The dashed line is a schematic isograd.

It is suggested that the deformation in the domal area at this time consisted mainly of extension parallel to the layering as indicated schematically in figure 5 (b). This interpretation, if correct, would explain the absence of the F_2 minor folds in the vicinity of the Bridgeport Synform, "H".

Early in the second deformational stage the three F_{2A} folds ("E", "F", and "G" in figures 4 and 5) formed along the hinge at the edge of the domal area. At the same time the low-grade rocks to the east were downdropped and compressed to form the Wepawaug Syncline ("I" in figure 5). The F_{2B} folds developed late in the second deformation stage as the domal rocks overrode the hinge area (figure 5, "J"). To the east, however, the Wepawaug Syncline continued to be compressed with only a single set of F2 minor structures being developed.

Stage 3. The large-scale features of the third deformational stage are less pronounced than of the preceding deformations. During the third deformational stage the area was warped by large, open, north-south trending F3 folds. These folds further deepened the Wepawaug Syncline and arched an area along the west edge of the southeastern belt as illustrated in figure 5 (d). As with the preceding deformations, the F_3 fabrics show that the metamorphism remained in the established patterns.

Stage 4. Regionally the fourth deformational stage is of little importance and seems to be represented only by the minor F_4 kink folds. The marked difference in the style of these folds is taken as an indication that the physical conditions at the time of the fourth deformational stage differed from the conditions during the first three deformational stages. The fabrics associated with the F_4 structure are also quite different. There is little evidence of recrystallization; the mineral grains are commonly strained and bent. The east-west trend of these folds suggests a north-south compression during the fourth deformation stage.

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STOP DESCRIPTIONS

Stop 1. (20.24N-53.87E) Long roadcut on Route 69 opposite Lake Watrous, 0.9 miles north of intersection of Dillon Road and Route 69.

This stop is in the Wepawaug Schist on the east limb of the F_2-F_3 Wepawaug Syncline (the Wepawaug Syncline is marked I in the geologic cross-sections of figures 5 and 6). The rocks are of the chlorite grade of metamorphism. Lenses of marble and granite (Woodbridge Granite) are found at the south end of the roadcut.

Evidence for three of the four primary minor fold systems that are found in the New Haven-Naugatuck-Westport area may be seen here. The dominant foliation is a closely spaced F_2 axial-plane crenulation cleavage. In the northern portion of this outcrop F_2 minor folds, associated with this cleavage, may be seen. Streak lineations at an angle to the F_2 fold axes are F_1 lineations parallel to F_1 fold axes. The F_1 folds are difficult to discern on the natural surfaces of the rock, but are easily seen in polished sections. Very prominantly displayed here are the F_4 kink-bands which distort the F_2 foliation.

Stop 2. (16.34N-54.29E) Roadcut on eastbound entrance ramp of Connecticut Turnpike, interchange 42, at Campbell Avenue.

This muscovite-chlorite schist belongs to the Lower Member of the Derby Hill Formation (Savin Schist of Burger, 1967). As with stop 1, these rocks are at the chlorite grade of metamorphism and are on the east limb of the Wepawaug Syncline.

The dominant minor structures here are F_2. The foliation is a crenulation cleavage parallel to the axial planes of F_2 minor folds. These F_2 structures largely obscure the older minor structures. However, there are a few folded F_1 minor folds that can be seen here. In this vicinity rather weakly developed F_3 and F_4 minor folds are sometimes found (e.g., roadcut on Blue Hill Road, 200 feet south of the railroad tracks, 0.6 mile south of here).

Stop 3. (15.35N-54.36E) Outcrop along shore of Long Island Sound adjacent to Ocean Beach Road, 200 feet east of intersection of Savin Avenue and Ocean Beach Road.

As with stop 2, these rocks are of the Lower Member of the Derby Hill Formation and have been metamorphosed to the chlorite grade. Between stops 2 and 3, the F_2 minor structures largely die out and the only evidence for the F_2 deformation here is the presence of scattered, very weak crenulations. The dominant minor structures are F_1.

Stop 4. (16.45N-52.56E) Small roadcut on Lambert Road, 0.1 mile north of intersection of Tyler City Road and Lambert Road.

This small roadcut in the Wepawaug Schist (chlorite grade of metamorphism) is of interest because all of the four primary minor fold systems are found here or in the immediate vicinity. The most obvious of the minor structures are tight F_2 folds with an axial-plane crenulation cleavage. These F_2 folds largely obscure the older F_1 minor folds, which are generally discernable only in polished sections. However, the streak lineation here is parallel to the F_1 fold axes. Very weakly developed F_3 crenulation cleavage deforms the F_2 cleavage. Please do not sample the F_3 cleavage; it is quite easily removed and there isn't much of it left. Somewhat questionable F_4 kink-bands are found here. More definite F_4 minor structures are found a short distance away on Tyler City Road, 400 feet west of the intersection with Lambert Road.

Stop 5. (15.07N-50.29E) Long roadcut on westbound entrance ramp to the Merritt Parkway, interchange 53.

Here, the thinly laminated quartzose muscovite schist and paragneiss of the Oronoque Member of the Derby Hill Formation are at the kyanite grade of metamorphism. This stop and stops 6 and 7 are located on the east limb of the Bridgeport Synform and on the west limb of the Wepawaug Syncline "H" and "I", respectively, in figures 4 and 5. The schistosity here is an F_1 axial-plane schistosity. On top of the outcrop minor F_1 similar folds are visible on the glacially polished surfaces. The crenulations are F_3 and the kink-bands are F_4. In roadcuts on the Merritt Parkway one mile west of here, the F_3 minor structures are more pronounced and locally a coarse F_3 crenulation cleavage is developed.

Stop 6. (17.70N-51.03E) Roadcut on Route 110; 0.9 mile south of intersection of Route 8 and Route 110.

Here we see the Wepawaug Schist at the kyanite grade of metamorphism. As with stops 5 and 7, this stop is situated between the Wepawaug Syncline (to the east) and the Bridgeport Synform (to the west). The dominant minor stuctures are F_1. The F_1 axial-plane schistosity is vertical. Axes of the F_1 folds, which may be seen from the top of the exposure, plunge down-dip. The very weak crenulations are believed to be F_2.

Stop 7. (17.25N-50.96E) Long roadcut on Route 110; 0.7 mile south of intersection of Route 110 and Route 8.

These rocks have been metamorphosed to the kyanite grade and belong to the Lower Member of the Derby Hill Formation (seen at stops 2 and 3 in chlorite zone). The minor structures are F_1, F_2 (?), and F_4.

Stop 8. (13.79N-45.90E to 13.59N-45.77E) Series of roadcuts on the Merritt Parkway between the Morehouse Highway overpass and interchange 45.

With this series of roadcuts we begin in the Fairfield Formation on the northwest limb of the inverted F_1 Fairfield Syncline ("A" in figures 5 and 6) and cross into The Straits Schist in the core of this fold and then back into the Fairfield Formation on the southeast limb of the fold. Both contacts between the Fairfield Formation and The Straits Schist are marked here by massive amphibolite and quartzite at the top of the Fairfield Formation. Elsewhere, marble and calc-silicates are also found in the uppermost portion of the Fairfield Formation.

In this area the Fairfield Syncline is folded by a large recumbent F_{2B} fold. The axial-zone of this fold is exposed in this series of roadcuts. The schistosity in this area is in the axial plane of F_{2B} minor folds.

Stop 9. (13.42N-45.76E) Adjacent to Blackrock Turnpike, 0.2 mile southeast of interchange 44-45 of Merritt Parkway.

These recumbent minor folds in the Fairfield Formation are in the axial zone of the major F_{2B} recumbent fold seen at stop 8. These rocks were metamorphosed at the sillimanite grade.