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Stratigraphy and Structure of the Ware-Barre Area, Central Massachusetts

Robinson, Peter

Field, Michael T.

Tucker, Robert D.

Trip P-4

STRATIGRAPHY AND STRUCTURE OF THE WARE-BARRE AREA, CENTRAL MASSACHUSETTS

by

Peter Robinson
Department of Geology and Geography
University of Massachusetts
Amherst, Massachusetts 01003

Michael T. Field
230 Halligan Ave.
Worthington, Ohio 43085

Robert D. Tucker
Department of Geology and Geophysics
Yale University
New Haven, Connecticut 06520

INTRODUCTION

The purpose of this trip is to consider a sequence of lithic units in a traverse eastward from the well known belt of the Bronson Hill anticlinorium into the heart of the Merrimack synclinorium. The mapping covered was part of a larger project to carry stratigraphic and structural correlation across central Massachusetts from the Connecticut Valley to the Worcester area, which became incorporated in the U.S.G.S. project to compile a Bedrock Geologic Map of Massachusetts. The initial steps were taken by Field (1975) in the Ware area, one of the few places where correlation efforts are not entirely blocked by large plutons (Figure 1). Tucker (1977) carried the correlations of Field northeastward to the crest of the Oakham anticline and eventually to the Mt. Wachusett area, though that is not to be covered here.

Three stratigraphic-structural interpretations have been applied in recent years to this large region, in which, for the most part, the bedding and foliation dip west toward the Bronson Hill anticlinorium (Figure 2).

The interpretation proposed by Peper et al. (1975) and more recently supported by Pease and Barosh (1981) is that the west-dipping sequence is essentially homoclinal with tops west and is tens of kilometers thick even though broken by a number of thrust faults. This thick section is then in fault contact with the very thin, better known, stratigraphic sequence of the Bronson Hill anticlinorium along the Bone Mill Brook fault at the east edge of the Monson Gneiss.

2) The interpretation proposed by Field (1975), Tucker (1977) and Robinson (1979), is that the sequence of the Merrimack Synclinorium, like that of the Bronson Hill anticlinorium, is involved in three very complex

phases of folding: A) early nappes with east-over-west overfolding that caused many repetitions of units, followed by B) backfolding of early axial surfaces toward the east, to create the dominant west-dipping attitudes, followed by C) tight folding associated with the rise of the gneiss domes. Within this interpretation it is also recognized that there are important facies and thickness changes, particularly within the Silurian, between the thinner western sequence and the thicker eastern sequence of the Merrimack trough.

3) The interpretation proposed by Rodgers (1981) is that the stratigraphic repetitions recognized in 2) above are the result of fault imbrication by the thrust faults in 1) above, and that the whole complex should be viewed as an accretionary prism in which underthrusting and sedimentation were in part contemporaneous through Ordovician, Silurian and Devonian time on the east side of an island arc in the position of the Bronson Hill anticlinorium. Robinson and Tucker (in press) have prepared a detailed reply to this proposal.

An additional question for detailed attention has to do with correlations to western Maine and whether certain rocks assigned to the Littleton and Partridge Formations might suitably be assigned to the Perry Mountain Formation and C Member of the Rangeley Formation.

ACKNOWLEDGEMENTS

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Figure 1. (turn next page) Generalized bedrock geologic map of part of central Massachusetts, showing route of field trip and location of cross section of Figure 2. Same symbols are used in Figures 7, 9, 11, and 12 together with letter symbols in parentheses.

EXPLANATION

Jurassic

Diabase dikes (Jd).

Devonian

Foliated granite gneiss, biotite gneiss (gg).

Gneiss of Ragged Hill (Drh).

Coys Hill Porphyritic Granite (Dchg). Separate pattern for lenses of mafic gneiss (Dchm).

Granodiorite, tonalite (Dht).

Hornblende gabbro, diorite (Dgdi).

Lower Devonian

Littleton Formation

Feldspar Gneiss Member (Dlf).

Orthopyroxene Gneiss Member (Dlo).

Pelitic Schist Member (Dl).

Silurian

Fitch Formation (Sf).

(Subzone B)

Paxton Formation

Sulfidic Schist Member (Spss)

Granulite Member (Sp). Amphibolite where separately mapped (Spa).

White Schist Member (Spw). Quartzite-Rusty Schist Member (Spqr).

(Subzones C and D)

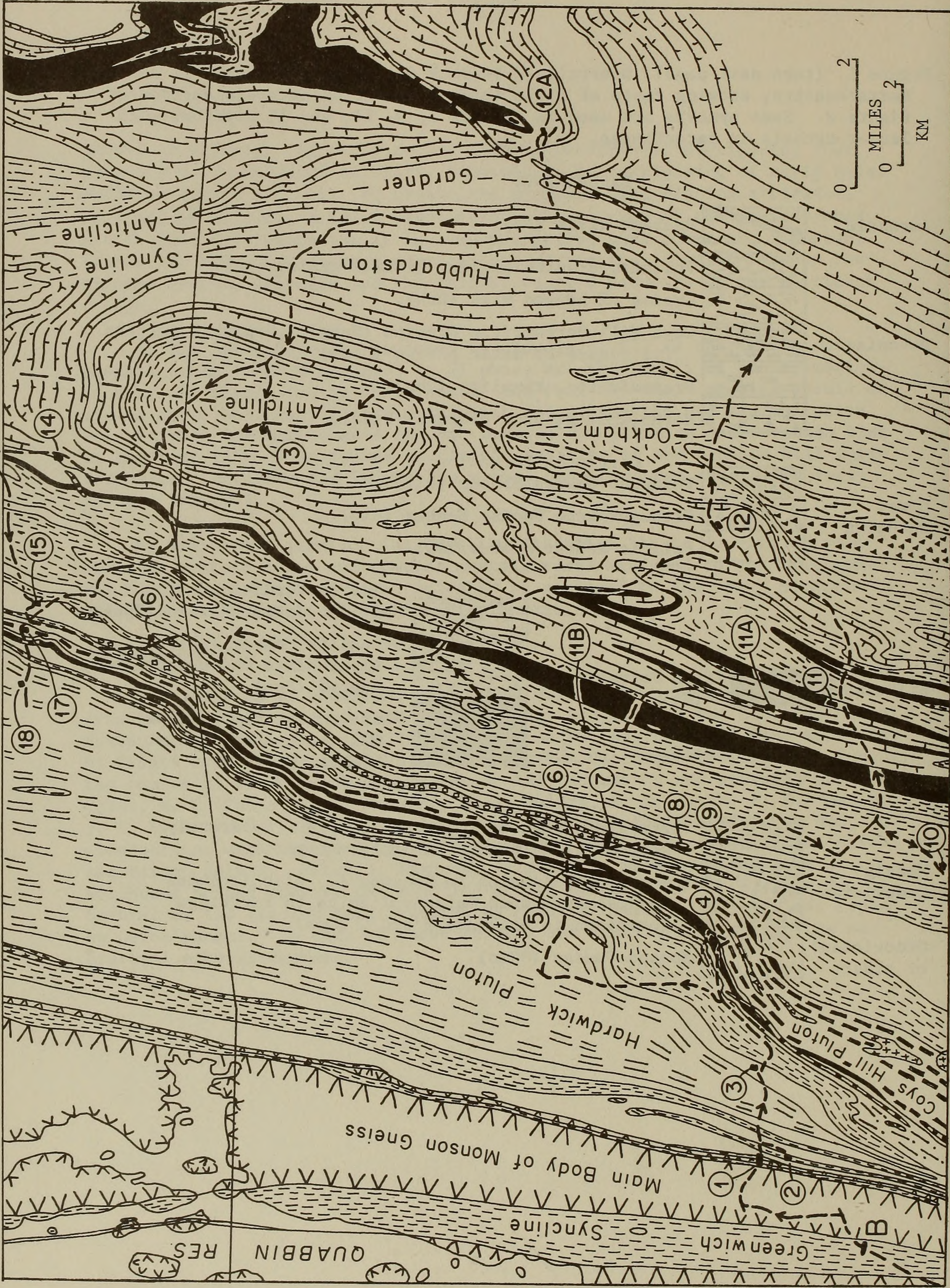
Middle Ordovician

Partridge Formation (Ops, Opsa, Opl). Separately mapped felsic gneiss in different pattern.

Ammonoosuc Volcanics in Subzone A. Also includes separately mapped mafic volcanics in Partridge Formation in Subzones B and C (Opa).

Ordovician? or older.

Monson Gneiss (OZmo).


Greenwich Syncline
QUABBIN RES
Main Body of Monson Gneiss
Hardwick Pluton
Coys Hill Pluton
Oakham Anticline
Hubbardston Syncline
Anticline
Gardner
Anticline
0 MILES 2
0 KM 2
B
1
2
3
4
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6
7
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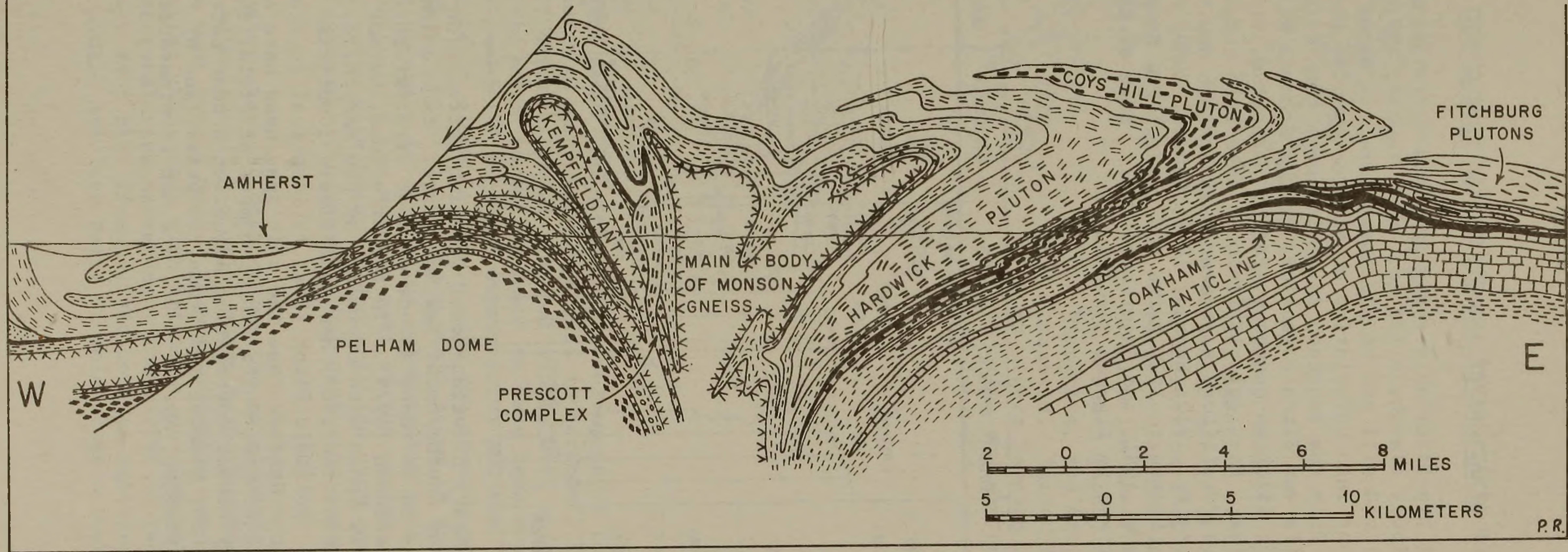


P4-5

Figure 2. Bedrock geologic cross section across central Massachusetts. Line of section (although not full length of it) is shown in Figure 1, and also in Trip P-3, Figure 1. In the two eastern straight segments the section follows the line of Quabbin Aqueduct Tunnel described in detail and sampled by Fahlquist (1935). Detailed sections on parts of this line are given by Field (1975) and Tucker (1977).

BRIEF SUMMARY OF STRATIGRAPHY AND STRUCTURAL DEVELOPMENT

Details of pre-Silurian stratigraphy and correlation problems have been covered extensively elsewhere (Field, 1975; Tucker, 1977, Robinson 1979 Robinson, 1981) and will not be discussed here. A major portion of recent research has gone into correlation of Siluro-Devonian rocks and particularly the transition from the sequence involving very thin Silurian strata (Clough Quartzite and Fitch Formation) on the Bronson Hill anticlinorium to the much thicker Silurian sequence (Paxton Formation, etc.) of the Merrimack synclinorium. Particularly fruitful have been comparisons with the similar but more fossiliferous sequences in western and central Maine (Moench and Boudette, 1970; Ludman, 1976; Osberg, 1980; Robinson, 1981) and more recently attempts to link Maine and central New Hampshire (Hatch, Moench, and Lyons, 1981, and in preparation). Some of these ideas are tentatively summarized in Figures 3 and 4.

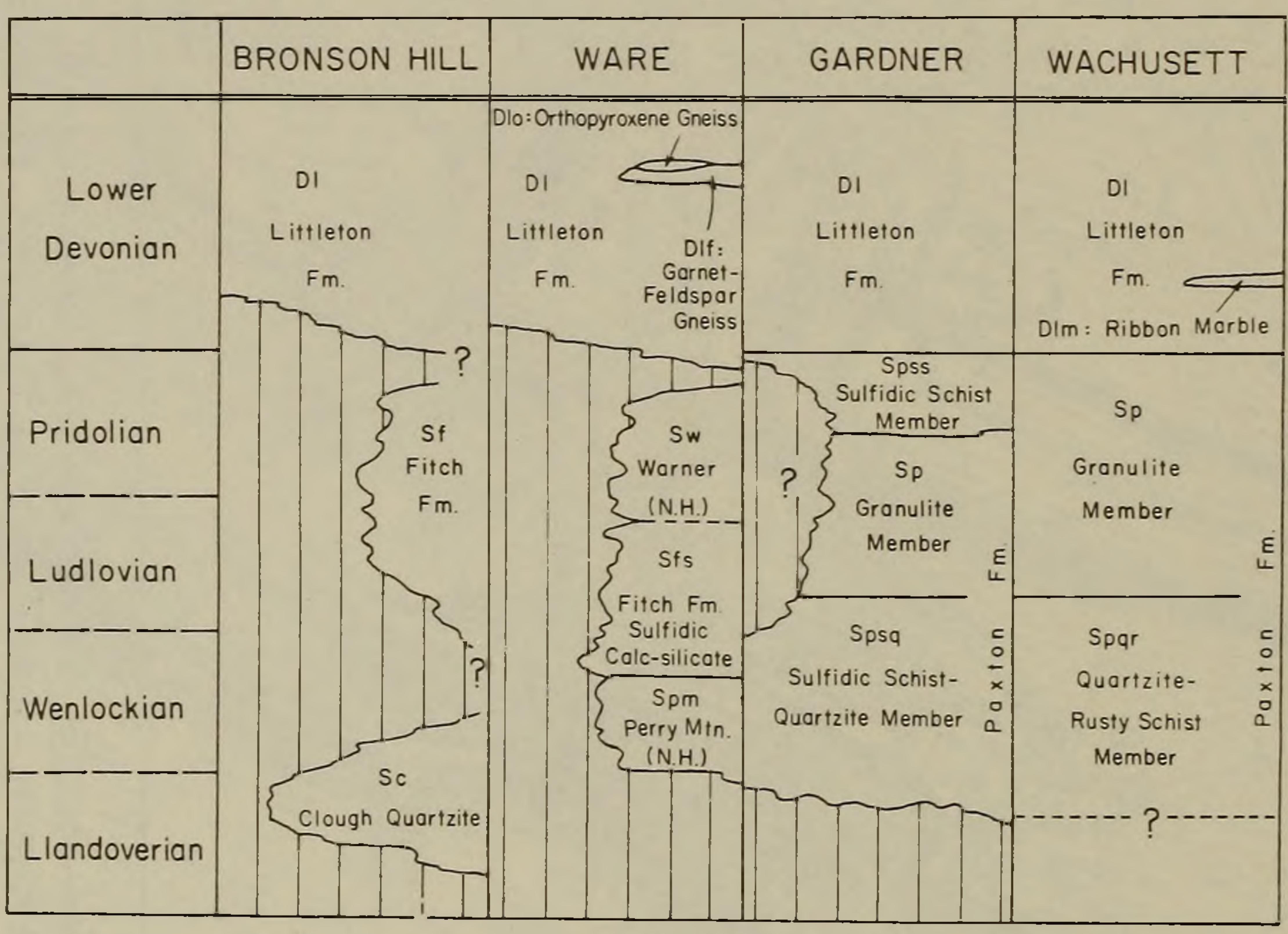


Figure 3. Preliminary Silurian-Lower Devonian correlation chart for central Massachusetts and southernmost New Hampshire. Each column represents the typical sequence to be found in one of four stratigraphic-tectonic subzones as defined by Robinson (1979). In the Ware Zone, Warner and Perry Mountain are only known with certainty in New Hampshire, and Peter Thompson (personal communication 1982) has tentatively identified Rangely C below Perry Mountain. Sulfidic Fitch (Sfs) is identical to Francestown of New Hampshire. In the Gardner Zone the unit Spsq used here and on the State Map is identical to Spw, White Schist Member of Field, used in this guidebook. Very recent correlation adjustments near bottom of the section suggested by Hatch, Moench, and Lyons, in press, and by P. H. Osberg, personal communication, April, 1982, are not incorporated.

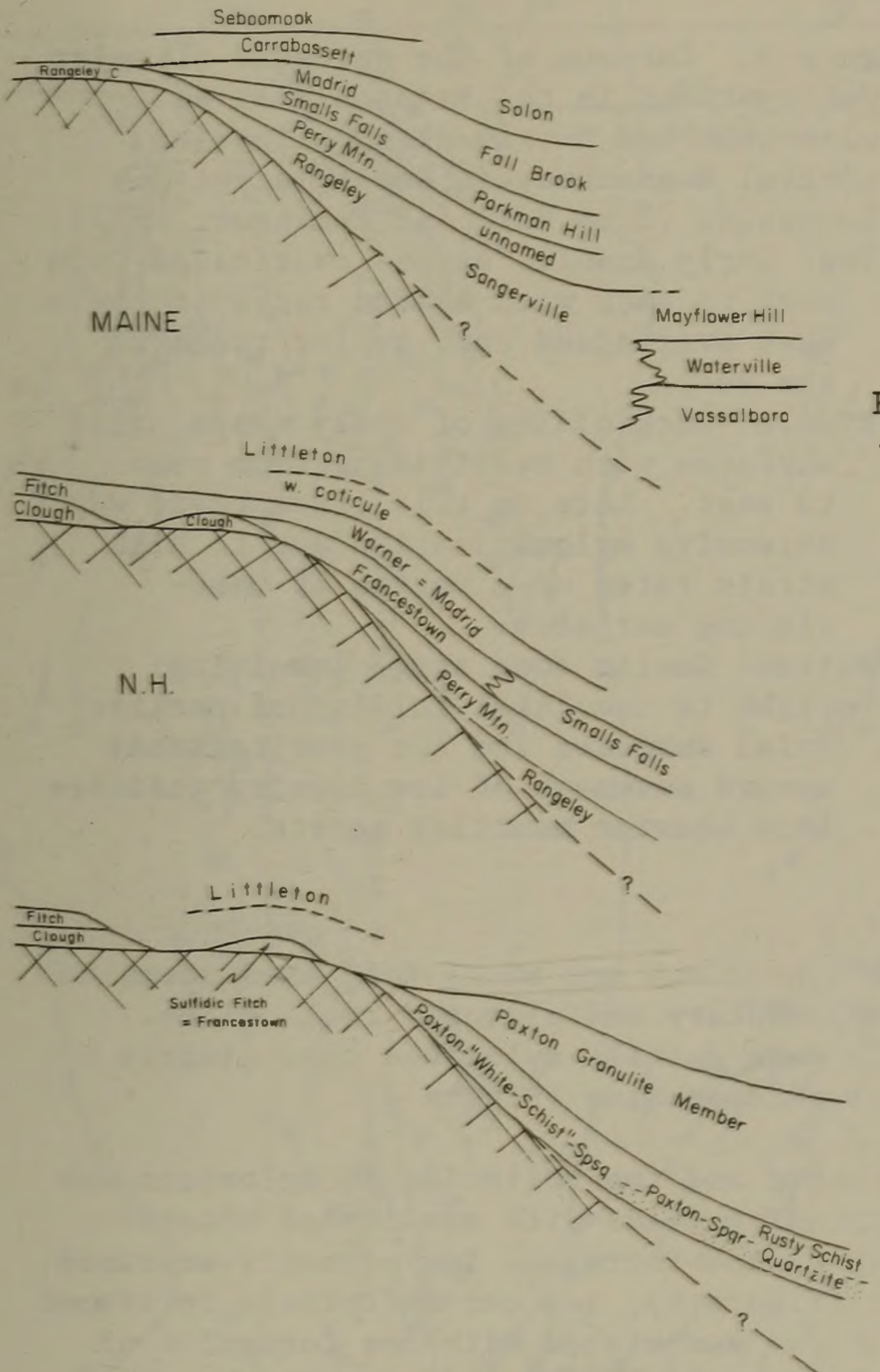


Figure 4. Restored schematic E-W stratigraphic profiles on the western margin of the Merrimack synclinorium showing comparative facies relations and unit names of Silurian-Lower Devonian rocks in western Maine, central New Hampshire, and central Massachusetts. Recent (1982) ideas on strata beneath the Rangely in Maine and New Hampshire are not included.

Some current ideas about the structural development of the region during the Devonian Acadian orogeny are summarized in cartoon form in Figure 5. The earliest stage of deformation was that of nappes with major east-over-west overfolding. This nappe formation seems to have been roughly contemporaneous with early stages of regional metamorphism and the intrusion of a series of quasi-concordant plutonic sheets. In the eastern part of the region, probably high in the pile of nappes, this seems to have been accompanied by rather low pressure facies series metamorphism with widespread production of andalusite. In the western part of the region it appears that hot, relatively dry, rocks were being folded westward over cool wet rocks to produce a major "metamorphic overhang" that persisted through later stages.

In the second major stage of deformation the axial surfaces of the earlier nappes were back-folded on a major scale into recumbent folds or nappes directed from west toward east. Peak metamorphic conditions seem to have been reached during this stage with extensive development of sillimanite-orthoclase-garnet-cordierite assemblages indicative of temperatures up to 700°C and pressures to 6 kbar from pelitic schists previously containing andalusite. In the middle and late parts of this stage a powerful E-W

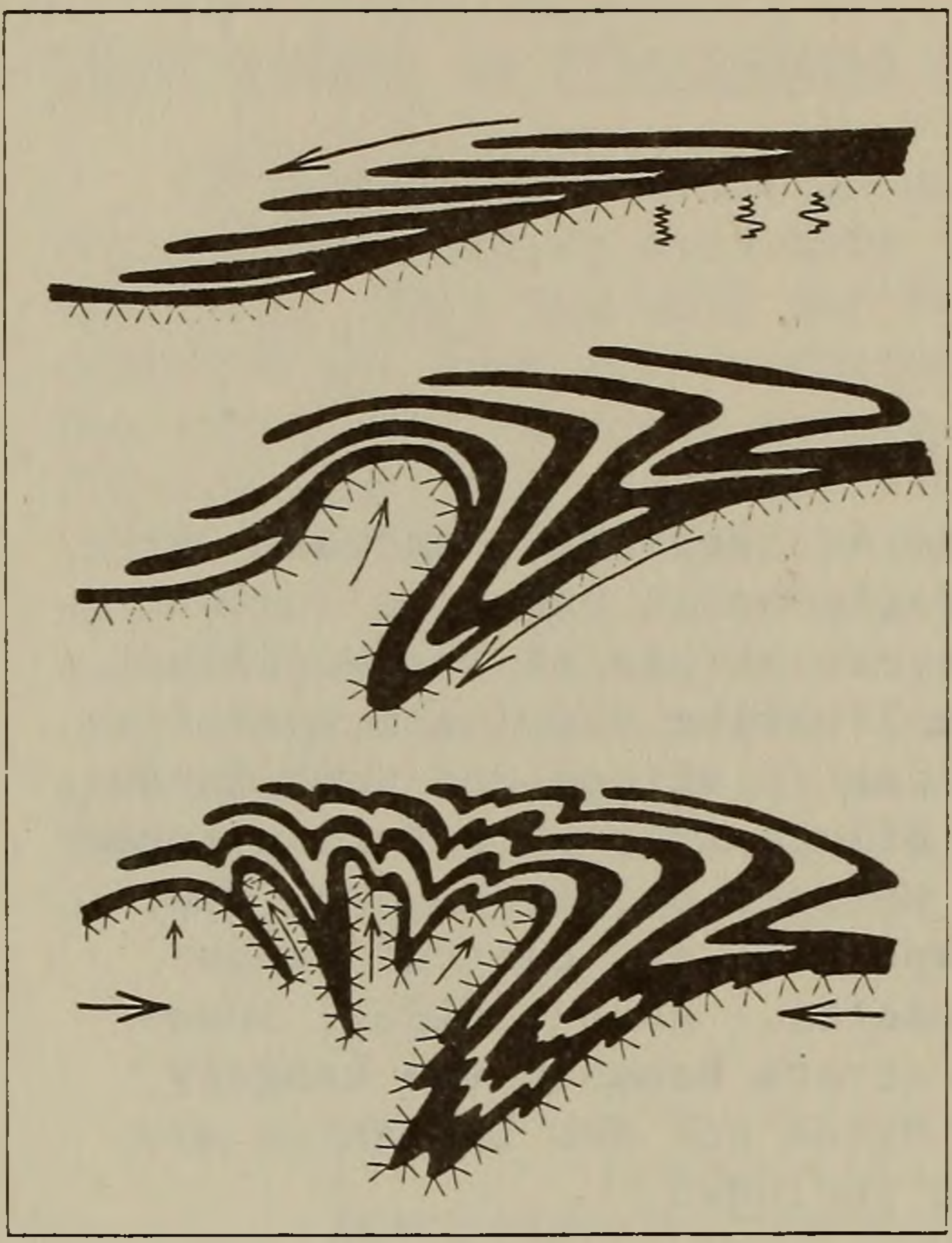


Figure 5. Cartoon of the sequence of major deformations in the Bronson Hill anticlinorium and Merrimack synclinorium, central Massachusetts and adjacent New Hampshire (from Hall and Robinson, 1982).
Top: Early Acadian nappes overfolded from east to west with heated rocks in the east overfolded onto cooler rocks in the west.
Middle: Backfolding of early nappe axial surfaces with overfolding from west to east. Late in this stage there was extensive mylonitization due to high strain rates on a series of west-dipping surfaces.
Bottom: Gneiss dome stage involving tight to isoclinal folding of earlier axial surfaces and the gravitational upward movement of low density gneisses into heavier mantling strata.

trending tectonic fabric of mineral lineations and minor fold axes seems to have been formed in metamorphosed sedimentary and plutonic rocks alike. This E-W fabric is also contained in some ductile mylonites that clearly truncate minerals formed during peak metamorphism (Figure 6).

Both the E-W trending linear fabric and the foliation in mylonites are deformed by a series of northeast-trending folds with associated mineral lineations. This northeast-trending system increases in intensity westward, obliterating the earlier E-W fabric (Figure 6), and can definitely be traced into the pattern of folds and lineations associated with the formation of gneiss domes and anticlines of the Bronson Hill anticlinorium in the third or dome stage of major regional deformation.

Involvement of Lower Devonian strata and the radiometric dates on early Acadian plutons (Lyons and Livingston, 1977; Daniel Lux, pers. comm. 1982) suggest the early stages of the Acadian orogeny took place 410-400 million years ago, synchronous with intense phases of the Caledonian Orogeny of Scandinavia. The Belchertown pluton, which truncates folds of the earlier stages of deformation, has an unmetamorphosed pyroxene-rich core that yields a zircon age of 380 million years (Ashwal et al., 1979). However, the outer part of the pluton was converted into a hornblende-biotite gneiss during the dome stage of deformation, and metamorphic hornblende thus produced yields a hornblende K-Ar cooling age of 361 million years. Thus, it appears that the Acadian Orogeny was not a brief, abrupt event (Naylor, 1971), but was prolonged over 40 to 50 million years, and roughly comparable in time of development to the European Alps.

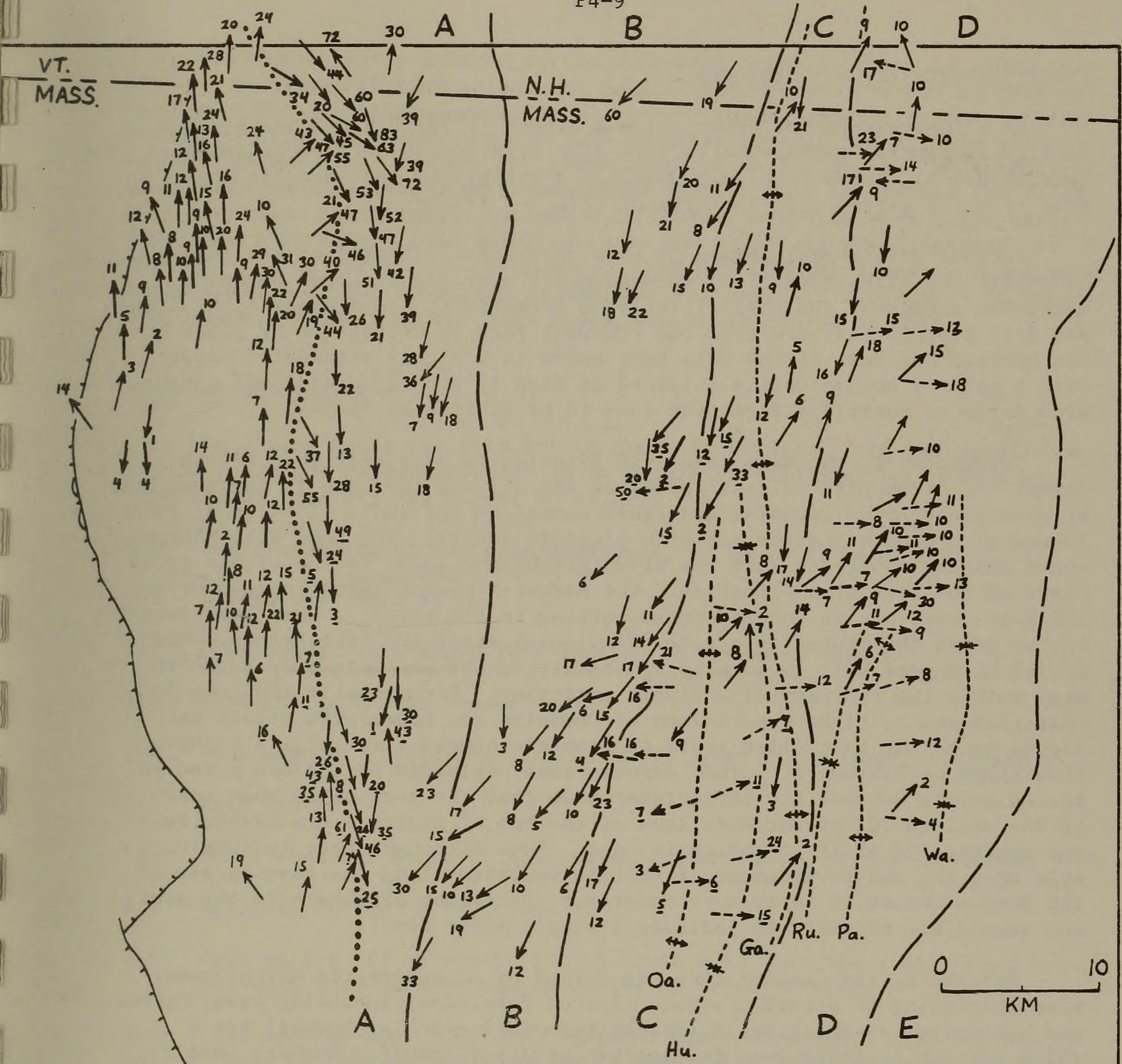


Figure 6. Linear structure summary map for central Massachusetts compiled from available data by Robert D. Tucker, 1978. Some available data in central, south-eastern and southern portions has not yet been added. Dashed arrows - trend and plunge of stage II lineations and minor fold axes. Solid arrows - trend and plunge of stage III lineations and minor fold axes. Each arrow represents mean trend and plunge determined from equal area plot of linear features measured in a single sub-area. Underlined number indicates selected individual measurement in area of sparse coverage or incomplete plotting. Long-dashed lines are boundaries between stratigraphic-tectonic subzones. Short-dashed lines are traces of axial surfaces of late anticlines and synclines: Oa. - Oakham anticline; Hu. - Hubbardston syncline; Ga. - Gardner anticline; Ru. - Rutland syncline; Pa. - Paxton anticline; Wa. - Wachusett syncline. Dotted line is trace of the "swirl" of stage III lineation in the Bronson Hill zone. The trace is defined as the approximate line where stage III lineation and minor fold axes plunge due east.

STRATIGRAPHIC-TECTONIC SUBZONES

As a convenience for description Robinson (1979) divided the bedrock geology of central Massachusetts into five stratigraphic-tectonic subzones (see Figure 6), based on Siluro-Devonian stratigraphy and tectonic style, four of which extend into the area of trip P-4 (Figure 1).

Subzone A is characterized by thin near-shore Silurian strata (Clough Quartzite and Fitch Formation) unconformably overlain by Lower Devonian quartzose sandstone and shale (Littleton Formation). In Subzone A, the Bronson Hill Zone, in the Ware area the dominant rock is Ordovician or older Monson Gneiss, but east of the main body there is a highly attenuated nappe with a core of Monson Gneiss (visited at Stop 1) and two additional nappes with cores of Partridge Formation (one to be visited at Stop 2).

In Subzone B, the Ware Zone, the Silurian is extremely thin (Fitch Formation, pyrrhotite calc-silicate) or absent, and the zone is characterized by widespread Lower Devonian quartzose sandstone and shale (Littleton) interleaved with some volcanics and with plutonic sheets. The Coys Hill pluton shows amazing coherence with the stratigraphy and seems to lie within or in place of the Littleton Formation. The Hardwick pluton seems concordant in the Ware area, but is locally cross-cutting to the north. When last seen to the south the pluton is a zone of mylonite about 100 feet across. The Gneiss of Ragged Hill is locally cross-cutting but the main body seems to stay within the confines of a single anticline. Structurally the zone is characterized by tight repetitions of Devonian and Ordovician strata believed to be the backfolded roots of Pennidic nappes structurally higher than those of Subzone A. Other deformational episodes of Subzone A can be traced across Subzone B. It is remarkable that the rock units that make up the western 70% of the Ware Zone at the top of Figure 1 are mashed into the western 20% of it at the south edge. Thus although there is considerable shearing and development of ductile mylonite along the east margin of the Monson Gneiss it is no more important there than elsewhere in the area, and should not be taken to indicate a single major fault.

Subzone C, the Gardner Zone, is marked by an apparently abrupt eastward thickening of Silurian strata (Paxton Formation) including basal shales and quartzites of Small Falls (Maine) type (White Schist Member) and a thick section of calcareous feldspathic strata (Granulite Member) possibly derived in part from an eastern volcanic source. Devonian (Littleton) strata contain more feldspathic shale, and less aluminous shale and quartzose sandstone than further west. Stratigraphic repetitions again appear to be mainly due to early-stage nappes, but apparently with a major contribution from second-stage backfolding, particularly in the poorly understood area in Figure 1 southwest of the Oakham anticline. Subzone C marks the abundant appearance of intermediate age E-W lineation of cataclastic aspect that becomes dominant in subzone D. This lineation appears to relate to the backfolding and/or the cataclasis that immediately followed it, and is clearly older than the NE-SW trending lineation related to dome stage folds that dominate further west. In Subzone C, northeast-southwest trending folds equated with the dome stage further west are warped over gently north-south trending foliation arches to form a broad, complex anticlinorium including the Oakham anticline, Hubbardston syncline, and Gardner anticline.

Stratigraphically Subzone D, the Wachusett Mountain Zone, is characterized by the same Silurian calcareous feldspathic (Paxton) strata as Subzone C, plus a thin continuous sulfidic quartzite (Paxton quartzite-rusty schist member). Silurian strata are overlain by metamorphosed black shale of probable Devonian age, in which are interleaved extensive sheet-like intrusives of biotite tonalite and biotite-muscovite granite that constitute the Fitchburg plutons. Structurally Subzone D is characterized by very tight early isoclines with nearly flat axial surfaces and by a late synclinal axis at the location of the Fitchburg plutons. Dominant mineral lineations and minor folds trend E-W, but locally N to NNE trending eastward overturned to recumbent folds, probably of the dome stage, are superimposed on this.

ROAD LOG FOR TRIP P-4

The entire route for trip P-4 is shown in Figure 1. To get details on how to reach the beginning point (B in Figure 1) read instructions in the road log of Trip P-3 and Figure 30 of Trip P-3.

0.0 Begin road log at railroad underpass, on Route 32 (B on Figure 1).

0.1 Bridge over Ware River.

1.2 Crossroads, turn sharp left (north) on Anderson Road.

1.5 Road cut in Monson Gneiss on right.

2.2 Stop sign at T junction with Route 9. Turn right (east) on Route 9.

2.3 Ware Center.

2.6 Small road cut on left in hornblende amphibolite of Monson Gneiss.

2.8 Outcrops at and beyond crest of hill.

2.9 Park as far off on right side of Route 9 as possible. Walk back (west) to small road cuts in Monson Gneiss at crest of hill.

Stop 1. (45 minutes approximately) (Winsor Dam Quadrangle.) The purpose of this stop is to observe the sequence of rock units that occurs along the east margin of the main body of Monson Gneiss and has been traced continuously from the Mt. Grace quadrangle to here.

The Monson Gneiss at the crest of the ridge dips about 40° west and consists of plagioclase gneiss with magnetite and homogeneous hornblende amphibolite layers up to 30 cm thick that may be deformed dikes. A pervasive down-dip linear fabric especially notable in amphibolites is assigned to the backfold stage, but is locally confused by later slickensides. The sub-horizontal coarse linear fabric including quartz rods in gneiss is related to the dome stage. At the east end of the outcrop are post-metamorphic (Mesozoic?) fractures with secondary epidote.

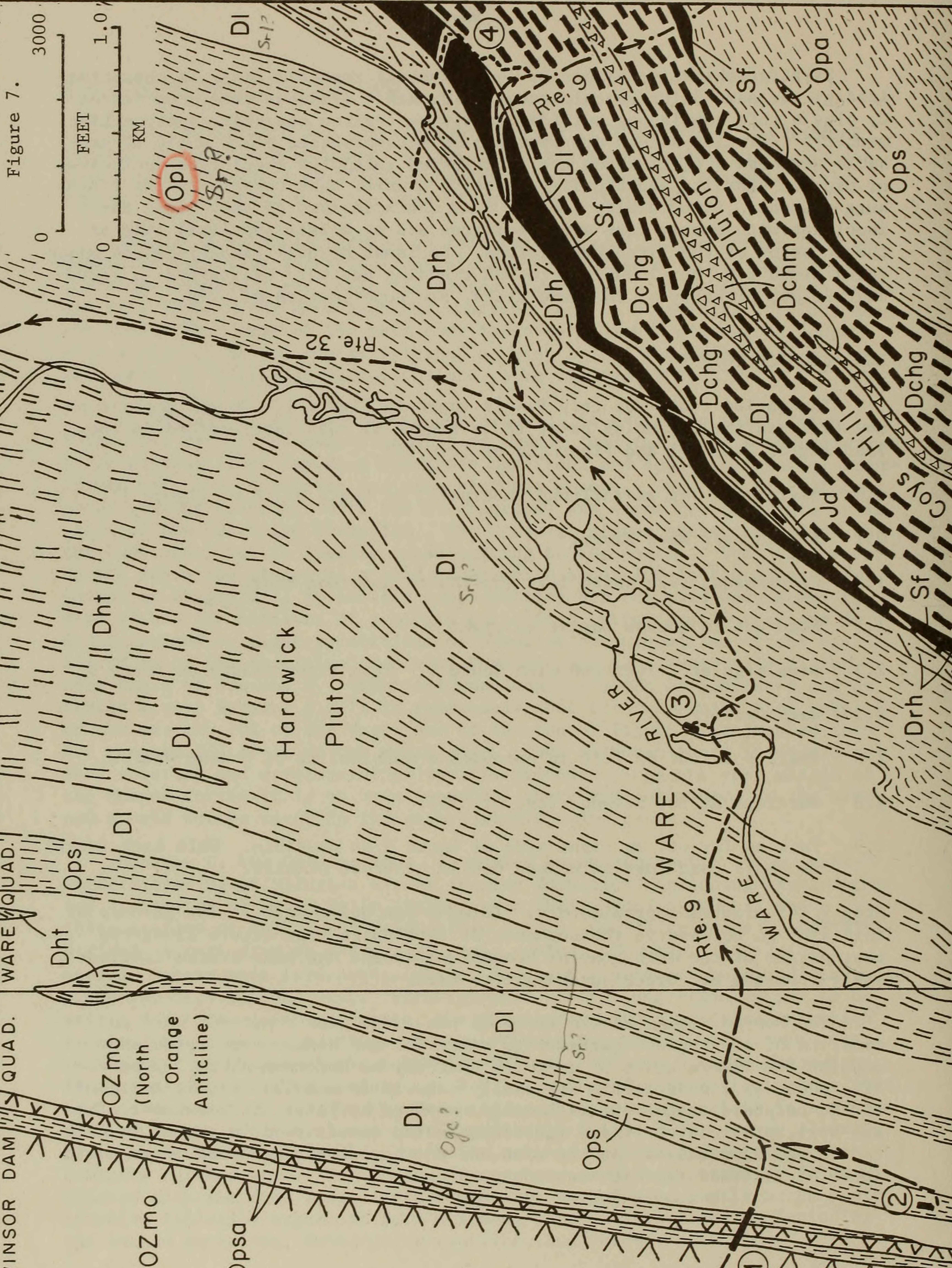

WINSOR DAM QUAD.
WARE QUAD.
OZmo
Opsa
OZmo (North Orange Anticline)
DI
Ops
Dht
Hardwick Pluton
WARE
WARE RIVER
Rte. 9
Rte. 32
Drh
Sf
Dchg
Dchm
Pluton
Jd
Opa
Opl
0
3000
FEET
1.0
KM

Figure 7.

Walk 350 feet east along road to modest outcrop of rusty Partridge Formation sulfidic schist and amphibolite. This belt of Partridge Formation, interpreted as a nappe stage isoclinal syncline, characteristically contains about 50% of amphibolite and other metamorphosed volcanics. To the north it also contains many of the bodies of olivine-spinel hornblendite described in detail by Wolff (1978). A few hundred yards north of here we have found the assemblage gedrite-orthopyroxene-garnet-plagioclase. Both down dip (backfold stage) and horizontal (dome stage) linear fabrics are present, and the west edge of the outcrop is a mylonitic schist with a strong down-dip fabric.

Walk 175 feet east and turn left (north) on obscure trail just east of bullrush swamp to large outcrop 50 feet north of road. This is the thinly laminated gneiss and amphibolite of the North Orange band of Monson Gneiss. Locally amphibolites are up to 20 cm thick. Contact relations in the Orange area (Robinson, 1963) demonstrated that this narrow band of gneiss is the core of an early nappe. This is exactly the same layer exposed near Route 2 and visited on NEIGC 1967 Trip B, Stop 8 and also the Caledonides in the U.S.A., Caledonide Orogen 1979, stop 6A. Note obscure isoclinal folds in foliation.

Return to highway and walk 150 feet east to driveway on left (north). In bushes northwest of driveway are small outcrops of rusty Partridge schist east of the gneiss band. On the side of the driveway is a small outcrop of pegmatite and mylonitized gray schist of the Littleton Formation with biotite, coarse sillimanite, garnet and K feldspar.

Cross highway (south) and enter Potter driveway. Behind house is an extensive outcrop of gray garnet-biotite-sillimanite schist of the Littleton Formation with abundant watery orthoclase megacrysts and some pegmatite. Subhorizontal (dome stage) lineation is evident.

Proceed east on Route 9.

3.1 Turn sharp right (south) on Gould Road (not Gould Street).

3.6 Turn right through gateway to Ware High School and park by outcrop.

Stop 2. (15 minutes approximately) (Winsor Dam Quadrangle). Rusty weathering sillimanite-pyrrhotite schist of the Partridge Formation in a narrow isoclinal anticline. For petrographic details see Trip P-3, Stop 2. The rock contains two different sillimanite lineations, an earlier E-W trending lineation of the backfold stage, and a later, more prominant southwest-plunging lineation of the dome stage.

Leave parking lot and turn left (north) on Gould Road.

4.2 Stop Sign. Turn right (east) onto Route 9.

5.1 Junction with Route 32 in center of Ware. Stay on Route 9 east.

5.5 Bridge over Ware River.

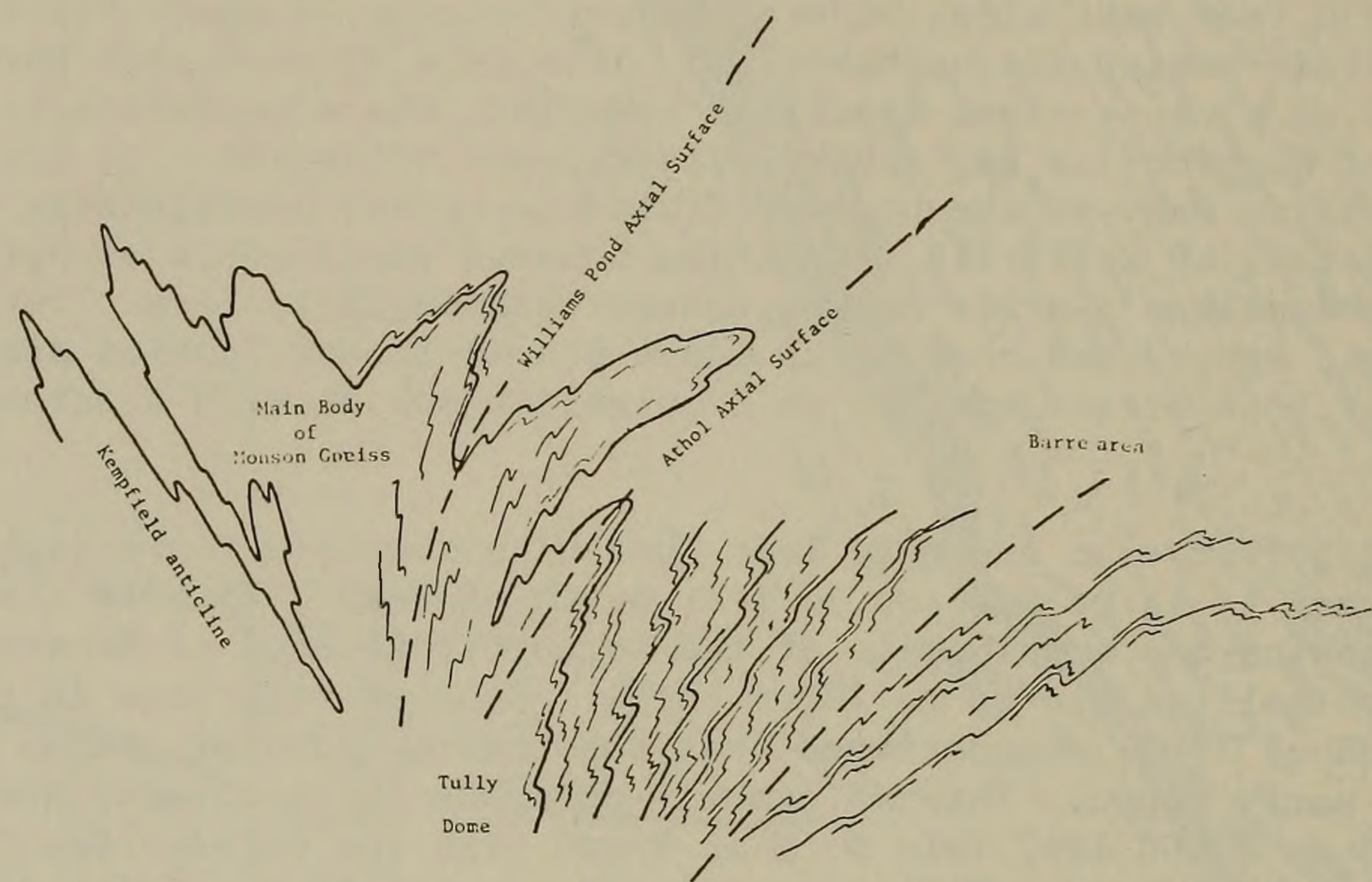


Figure 8. Diagrammatic section of relationships of dome stage fold asymmetry across part of west-central Massachusetts (from Tucker, 1977). East from the Athol axial surface to the central part of the Barre area, dome stage minor folds have east-side-up asymmetry. East of the Kruse Road syncline approximately, such minor folds reverse their asymmetry.

5.7 Turn right (south) into factory parking lot and park. Walk to north side of Route 9 and along sidewalk (west) to side street on north side which is on east side of Ware River. Walk up side street to rock garden and outcrop on left.

Stop 3. (15 minutes approximately) (Ware Quadrangle) The rock here is gray weathering sillimanite-garnet-biotite schist assigned to the Littleton Formation. Beautifully developed southwest plunging asymmetric folds in foliation of the dome stage have west dipping axial surfaces and show east-side-up movement sense. This fold asymmetry is characteristic of a huge region in central Massachusetts between the Athol and Barre axial surfaces as shown in Figure 8. In spite of the consistent pattern of asymmetries we do not understand their full significance and we have not located many major fold hinges related to them.

Leave parking lot. Turn right (east) onto Route 9.

6.7 Junction. Route 32 turns left. Stay on 9.

7.4 Low outcrops on left. Sulfidic Fitch Formation.

7.6 Left turn across traffic to dirt road which is old Route 9.

7.7 Stop just before crest of hill where outcrop appears on both sides of road. Pull well over as normal automobiles will be left here for several hours.

Stop 4. (1 hour 15 minutes approximately) (Ware Quadrangle) The purpose of this stop is to examine the sequence of lithic units westward from the Coys Hill Granite. In the western part of this traverse there will be a chance to examine rocks which we feel have the best chance to be re-interpreted as Perry Mountain or Rangeley equivalents, both because of their lithology and because a much more certain correlation with Perry Mountain-Rangeley has been made by Peter Thompson (pers. comm. 1981) along strike in the Monadnock area.

Walk north on wood road that is closest to rock exposures on Old Route 9 and bear left into picnic site under huge overhangs of Coys Hill Granite. At this locality and most in Massachusetts the Coys Hill is a coarse gneiss in which most of the K-feldspar megacrysts have tectonically rounded ends. The abundant garnet grains are probably metamorphic porphyroblasts rather than igneous phenocrysts to be seen in the center of the Cardigan pluton in New Hampshire.

Squeeze north between fallen rocks along east side of Coys Hill outcrop to trail that leads west. Turn north (right) on wood road at T intersection. Wood road runs directly along the contact between Coys Hill Granite and sulfidic Fitch Formation (=Francestown), and larger outcrops of Fitch may be seen in slope due west of pond. Follow wood road north to powerline and turn left (west and uphill) on powerline to small outcrop of Fitch Formation. Like the Francestown Formation, this rock is a graphite-rich feldspathic calc-silicate rock dominated by quartz and calcic plagioclase (usually An_{60-80}) with diopside, sphene, and pyrrhotite. Biotite, microcline, scapolite, actinolite, and calcite occur in a few samples but are much less important. Continue west and downhill along powerline over broken outcrops of Fitch Formation to third bump west of crest where there are large outcrops of the Gneiss of Ragged Hill. In the Ware area the main body of this gneiss occurs only in a narrow belt interpreted by Field as a nappe stage anticline, but within the anticline the gneiss locally cuts across the stratigraphy. The rock is a quartz-plagioclase (An_{20-30})-K feldspar gneiss with the composition of granite, granodiorite, or tonalite. Both biotite and garnet are characteristic, ilmenite is common, and several samples also contain sillimanite. The unit is interpreted as an Acadian intrusion that came in before or during the nappe stage and was present in all subsequent deformations.

Cross small stream and boggy ground to more outcrops of Gneiss of Ragged Hill but just beyond this cross into rusty feldspathic sillimanite-garnet schist mapped as Partridge Formation, Lyon Road type. In bed of stream just beyond is contact with gray weathering garnet-rich schist mapped as Littleton Formation. Travel off powerline around north side of next depression viewing large outcrops of quartzose gray garnet-sillimanite-orthoclase schist (± cordierite) with calc-silicate footballs. Could this be equivalent to the Perry Mountain Formation? Move southwestward back to powerline and across contact of overlying unit which is well exposed in powerline for several hundred yards and consists of brown to red-rusty weathering feldspathic schist with calc-silicate footballs mapped as Partridge Formation, Lyon Road type. Could this be equivalent to the Rangeley C of central New Hampshire? Southward this area appears to connect with the previous area of rusty schist in what was interpreted as a recumbent fold in which the gray schist hinges out.

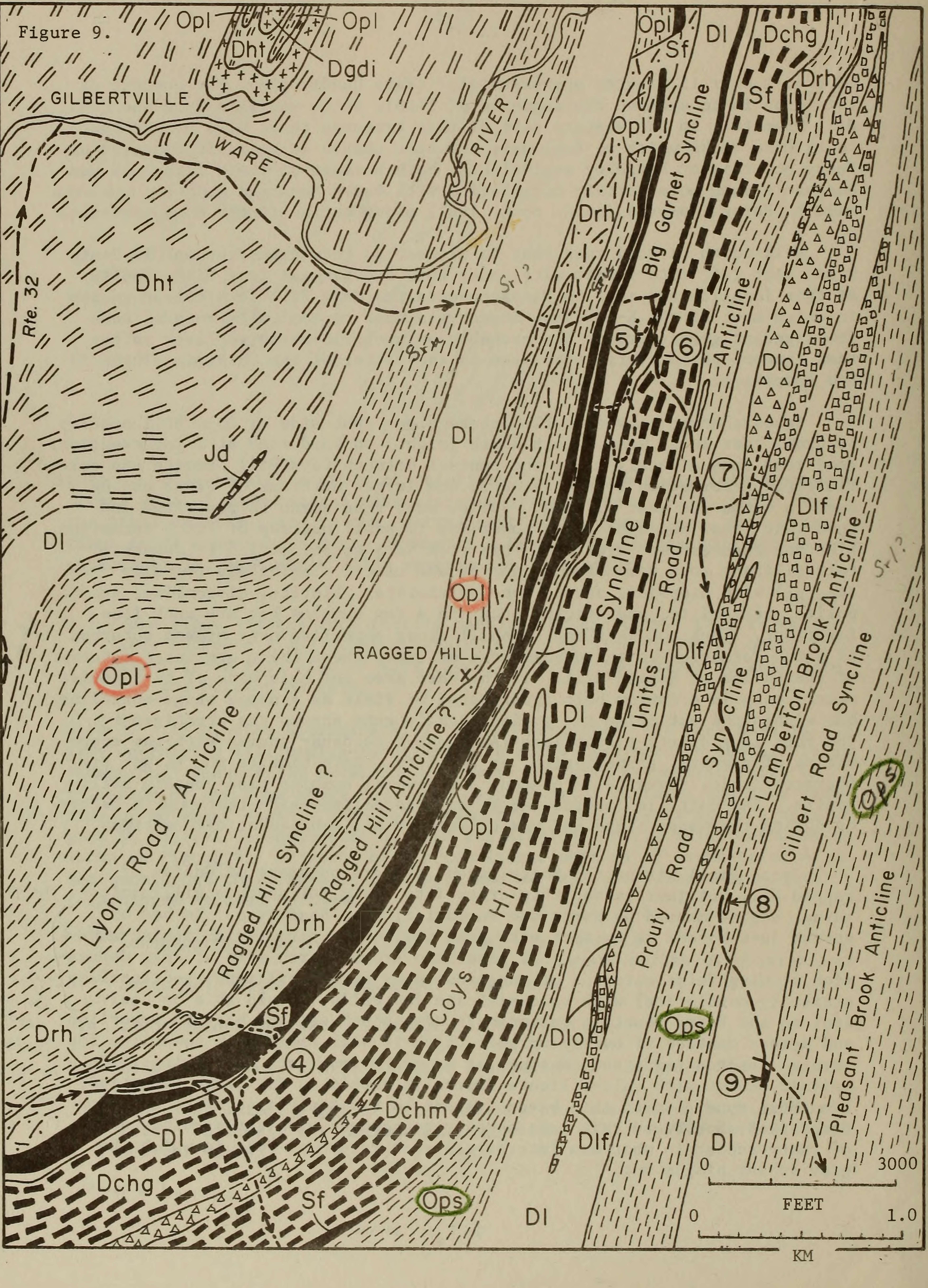


Figure 9.
GILBERTVILLE
WARE
RIVER
Rte. 32
Opl
Dht
Dgdi
Jd
Dl
Sf
Dchg
Drh
Big Garnet Syncline
Anticline
Dlo
Dlf
Unitas Road Syncline
Prouty Road Syncline
Lamberton Brook Anticline
Gilbert Road Syncline
Pleasant Brook Anticline
RAGGED HILL
Lyon Road Anticline
Ragged Hill Syncline ?
Ragged Hill Anticline ?
Coys Hill
Dchm
Ops
0
3000
FEET
0
1.0
KM

Return east along the powerline, avoiding highest point of ridge by trail on south side and continuing directly south to vehicles on wood road.

Only high clearance vans, trucks, and jeeps should go beyond here. After the traverse along Tucker Road (Stops 5-9) vans will return you here. Consolidate and bring lunch. Vans, etc. proceed east through pass.

7.8 Turn right (west) onto new Route 9 and retrace route.

8.9 Turn right (north) on Route 32. West Brookfield Town Line.

9.8 Hill to west (left) held up by tonalites of the Hardwick Pluton.

10.7 New Braintree Town Line.

11.9 Turn right (east) on New Braintree Road just before Route 32 crosses railroad and Ware River.

13.9 Turn right (south) onto Tucker Road. (Far end of pasture with large outcrop.)

14.0 Park at entrance to field on right or if there is no room drive up short steep section of road to good parking and walk back.

Stop 5. (1 hour approximately) (Ware Quadrangle) Lunch will probably be held here before the walk. Walk west and northwest through pasture to large knob outcrop of Big Garnet Member of Littleton Formation. For detailed discussion of petrology see Trip P-3, Stop 3. Walk south off outcrop and on crude road through pasture several hundred yards to flagged route that cuts westward across brook to east-facing cliff of Big Garnet Member. Easy ascent and descent of cliff to see Fitch Formation above the Big Garnet Member. Near contact the Big Garnet Member has less garnet and is more quartzose, with possible but improbable graded bedding. From base of cliff follow flagged route along slope to small excavation showing Fitch Formation below the Big Garnet Member. South of here 0.3 mile the two belts of Fitch merge around the end of the Big Garnet Member, forming one of the few recognizable hinges of a nappe stage fold in the Ware area. This map pattern and structural interpretation of this part of the Ware area are illustrated in exaggerated fashion in Figure 10.

From excavation follow flagging southeast to outcrop where coarse garnet rock just above Coys Hill pluton can be seen, then east to large outcrop of Coys Hill granite. Follow flagging across brook to east and then follow rough woodroad north and back to vehicles. Note loose blocks in pasture of white sulfidic sillimanite-rich schist which come from dip slope of the Fitch Formation. These pelitic interbeds are not common but they do suggest a transition to the correlative White Schist Member of the Paxton Formation (Smalls Falls equivalent) to be seen at Stop 11.

From pasture entrance drive up steep rise noting small outcrop and dip slope surface of sulfidic Fitch on right.

14.1 Outcrop of Big Garnet Member of Littleton Formation in bed of road.

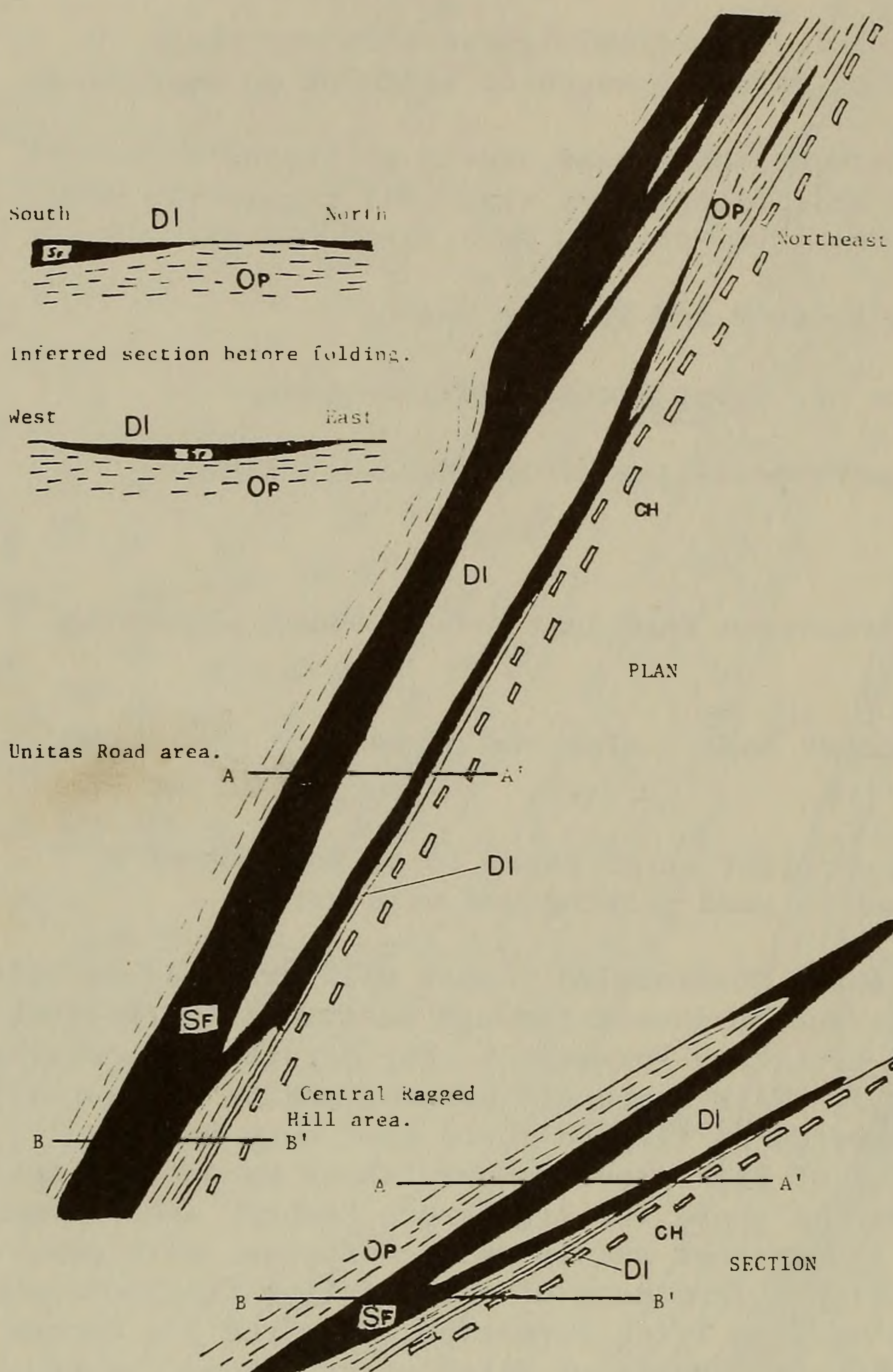


Figure 10. Exaggerated diagrammatic map and section of the Big Garnet syncline and the Fitch Formation with the Gneiss of Ragged Hill not shown. The thinning of the Fitch Formation to the east and west, and next to the Littleton Formation in the northeast, is shown as it is and as it is inferred to have been before nappe stage folding. Coys Hill Granite (CH) is believed to occupy the stratigraphic position of the Littleton Formation.

Stop 6. (15 minutes approximately) (Ware Quadrangle) This is the upper contact zone of the Coys Hill pluton. The contact lies about 20 feet east of the road. Walk back (north) 100 feet and take small trail 100 feet east to small clean exposure of highly foliated Coys Hill Granite. Outcrops in front of vehicles (south) and below the road on the west side are Littleton Formation with garnets up to 5 cm diameter.

Continue up Tucker Road past several outcrops of Coys Hill Granite and over several dips and rises.

14.5 Stop by north end of 10-20' rib of rusty schist on right. Park on right.

Stop 7. (1 hour approximately) (Ware Quadrangle) Examine rib of rusty weathering feldspathic schist of the Partridge Formation. This lies directly east of the Coys Hill Pluton and forms the core of the Unitas Road anticline. Typical schists contain sillimanite, orthoclase, plagioclase, biotite, garnet, graphite, and pyrrhotite.

Walk southeast on Tucker Road. At 200 feet note roadbed outcrop of gray-weathering Littleton schist. At 275 feet-roadbed outcrop of granitic gneiss. At 475 feet note roadbed outcrop of coarse gray garnet-sillimanite schist of Littleton Formation on west limb of Prouty Road syncline. Excellent loose pieces and small outcrops on northeast side of road (also poison ivy). Typical assemblage is quartz-sillimanite-garnet-biotite ± plagioclase ± orthoclase ± cordierite.

Cross over crest of rise and at 500 feet turn left (east) on flagged route through woods. Traverse 400 feet east then northeast along west-facing ledge to excellent exposure of coarse well layered garnet-sillimanite schist of Littleton Formation. Note well developed southwest plunging minor fold in foliation of the dome stage.

Cross east over crest of knob then about N70E to low broken outcrop of Littleton Formation Orthopyroxene Gneiss Member. Turn north-northeast on west side of knob 940' and traverse parallel to strike to twin blazed trees near second broken outcrop of hypersthene gneiss. Turn east-southeast and walk 100 feet to large low east-facing outcrop of Littleton Formation Feldspar Gneiss Member. This rock unit, which is widespread in the Prouty Road syncline as well as the Gilbert Road syncline is difficult to distinguish from foliated pegmatite. Here it consists mainly of quartz, orthoclase, plagioclase, and garnet, but elsewhere biotite is also present. The rock is interpreted as a metamorphosed rhyolite, and may indeed have been melted during metamorphism.

Continue at S70E about 200 feet across small valley and low ridge to small east-facing outcrops of sillimanite-garnet schist of Littleton Formation on east limb of Prouty Road syncline.

Return by same route to twin blazed trees. Turn N20E and proceed down ridge 300 feet to very large knob outcrop of Orthopyroxene Gneiss. According to Emerson (1917) (see Field, 1975, p. 61) this is the outcrop from which he collected a sample that was analyzed and appeared in Washington (1917) Professional Paper 99. The rock generally consists of andesine or labradorite, orthopyroxene, cummingtonite, and biotite with or without hornblende, quartz, or magnetite. The results of electron probe analyses of a sample from this outcrop are plotted in Trip 3, Figure 29, as a three-phase field cummingtonite-orthopyroxene-hornblende. An important aspect of this is the small difference in Mg/(Mg+Fe) ratio between cummingtonite (X_{Mg}=.69) and orthopyroxene (X_{Mg}=.66). The hornblende has X_{Mg}=.79 and tetrahedral Al of 1.33, and the plagioclase is An52. The two coexisting amphiboles have spectacular exsolution lamellae. The rock from Washington's (1917) analysis shows 50% SiO_2 and a norm or 1.11, ab 6.81, an 15.01, hy 69.66, ol 1.31, mt 2.09, il 1.52, ap 0.67. Since the analyzed rock contains no normative diopside, the original description of the rock as wehrlite seems hardly appropriate. In outcrop the rock shows a very weak foliation formed by elongate plagioclase patches. There are also numerous thin veins normal to foliation which seem to be filled with secondary cummingtonite. The Hypersthene Gneiss Member because of its stratigraphic limitations is considered most probably to have been a flow or flows of andesite of unusual composition, although an intrusive origin certainly cannot be ruled out.

Return to vehicles by same route past twin blazed trees.

Continue south on Tucker Road.

14.7 Town corner post on left side of road.

15.6 Obvious outcrop knob on left side of road.

Stop 8. (10 minutes approximately) (Ware Quadrangle) Exposure of Partridge Formation in center of Lamberton Brook anticline. Dominant rock type is quartz-plagioclase-biotite-garnet-pyrrhotite schist with or without sillimanite and graphite. A thin layer presumably derived from mafic volcanic rock consists of orthopyroxene (poikilitic crystals up to 6 cm long), cummingtonite, plagioclase, and biotite, and is exposed at the top of the knob.

Proceed south on Tucker Road.

16.1 Junction with Ragged Hill Road. Cross intersection onto Gilbert Road and park on right. Outcrop is in the southeast sector of the intersection. Watch out for poison ivy!

Stop 9. (10 minutes approximate) (Ware Quadrangle). Outcrop is beautiful gray coarse-grained sillimanite-garnet schist with well developed quartzose beds that is typical of the Littleton Formation in the Gilbert Road syncline. Further north in the Barre area this syncline contains the best example of graded bedding at Stop 16.

Turn around and head east on Ragged Hill Road (downhill)

16.7 Turn right (south) onto Wickaboag Road.

17.1 Sharp right turn (southwest) onto Snow Road (no sign, Stanwood King mailbox)

18.0 T junction with Route 9. To retrieve vehicles turn right (west) and drive 2.1 miles to crest of Coys Hill. To continue trip turn left (east).

18.6 Turn right (southwest) off Route 9 onto Route 67.

19.9 Large road cut of rusty schist on left. Park on right and cross road. WATCH FOR TRAFFIC.

Stop 10. (10 minutes approximately) (Warren Quadrangle) Extremely rusty-weathering sillimanite schist of the Partridge Formation in the Pleasant Brook anticline. For detailed description of petrology see Trip P-3, Stop 5. This extremely friable rock type forms few natural exposures, which are dominated by more resistant granular schists and granulites. This belt of rock is the same one that passes through the village of Brimfield and was assigned to the Upper Schist Member of the Hamilton Reservoir Formation by Pomeroy (1977). The assignment of these rocks to the Ordovician has been strengthened by an Ordovician zircon age of 440 m.y. on a diorite sill, the Hedgehog Hill Gneiss, intruding these rocks in northernmost Connecticut (Pease and Barosh , 1981, p. 23).

FW-140

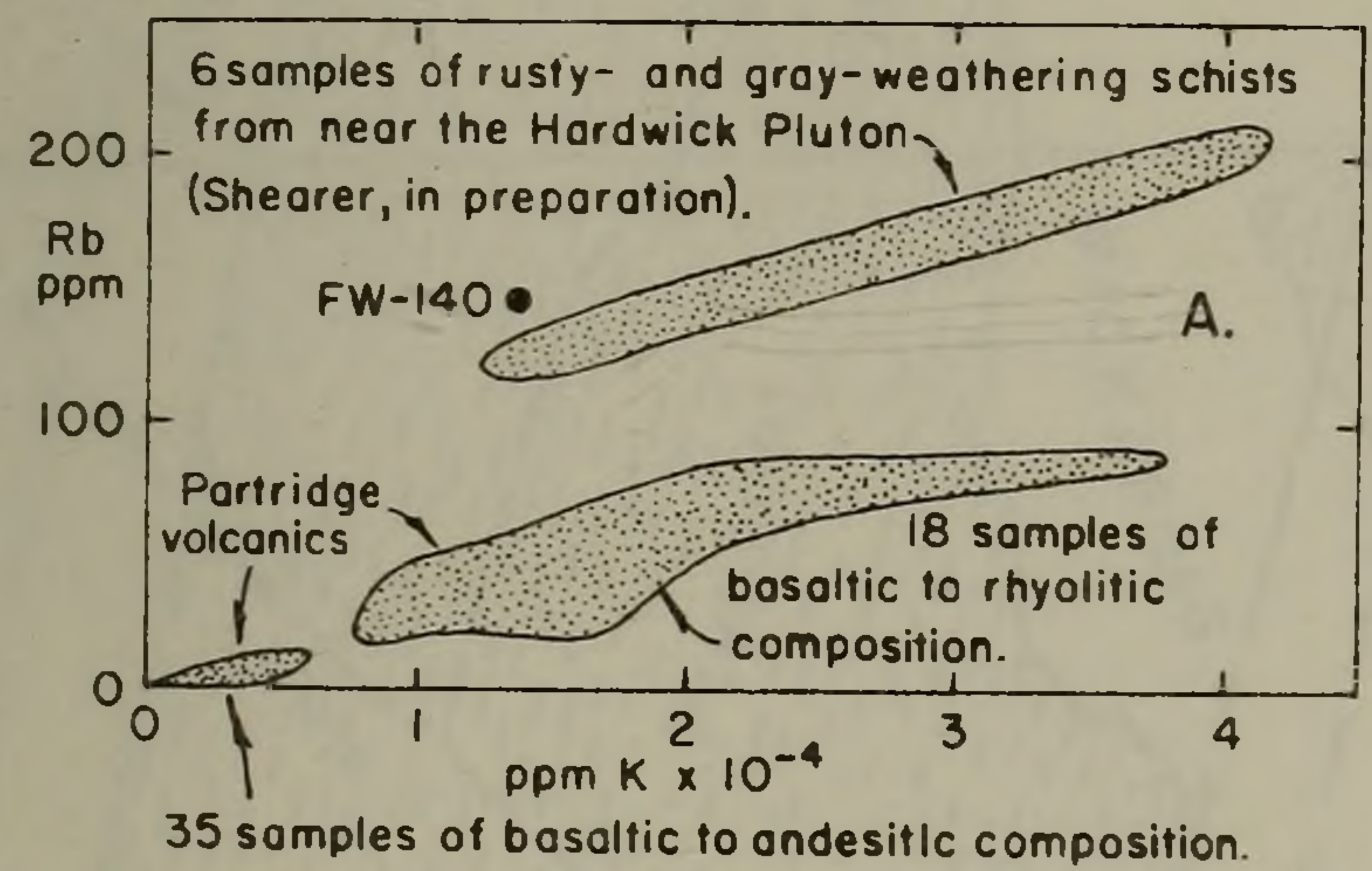
SiO_2	50.69
TiO_2	.66
Al_2O_3	8.38
Fe_2O_3*	.70
FeO	10.24
MnO	.18
MgO	22.03
CaO	4.64
Na_2O*	.20
K_2O	1.65
P_2O_5	.17
H_2O*	.32
Sum	99.81
Sr	35 ppm
Rb	145 ppm
K/Rb	95.3

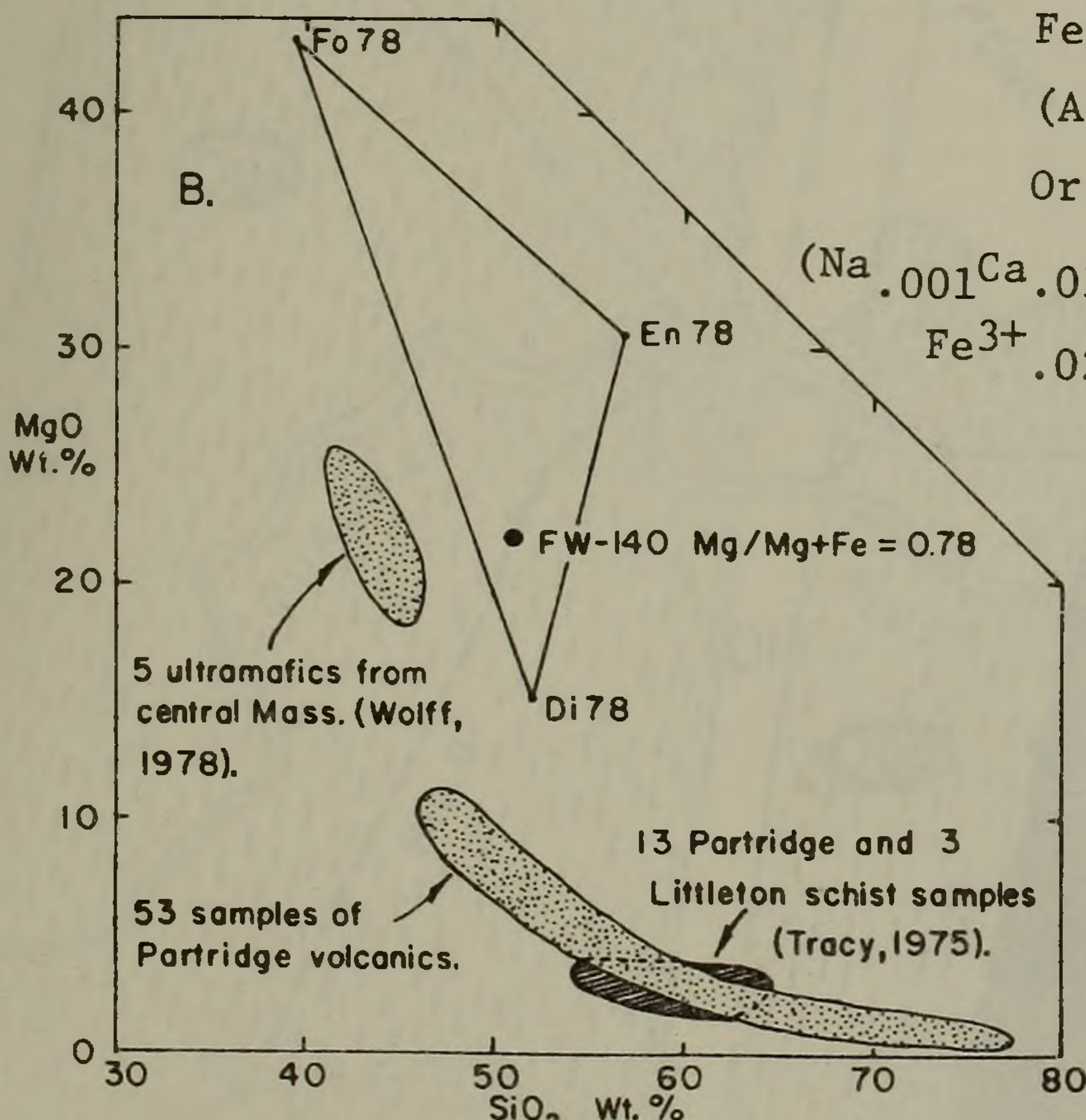
* Probe and mode estimates

The mafic, intermediate, and felsic gneisses in the Partridge Formation are probably metamorphosed volcanic rocks and sills. They range widely in composition from low-K olivine tholeites to rhyolites. Chemical trends of these rocks suggest that they have generally changed little in composition since deposition (except possibly alkalis). In contrast the orthopyroxene-plagioclase (An 87)-hornblende (nearly colorless, not cummingtonite as stated in the guidebook)-biotite-quartz gneiss (FW-140) at Stop 8 has a peculiar composition dissimilar to both Partridge volcanics and to analyzed ultramafic rocks in central Massachusetts.

Figure A shows that FW-140 is much richer in Rb than any other analyzed sample of the Partridge volcanics, and also richer in K than all but one other sample of basaltic composition. The similarity of Rb in FW-140 to local schists of similar K content suggests that Rb and possibly K diffused into the mafic rock from surrounding schists during or prior to metamorphism.

Figure B shows that the unusual composition of FW-140 is probably not due to mechanical mixing of mafic gneiss or ultramafics with schist or felsic rocks. FW-140 is much more silica rich than local ultramafics in the Partridge Formation, and therefore may be of dissimilar origin. FW-140 falls in a field defined by olivine and two edge-member pyroxenes with Mg/Mg+Fe ratios identical to the rock, suggesting that it is ultimately of cumulate origin.





Hornblende composition. $X_{Mg}=0.87$

$(K_{.028}Na_{.093})_{.121}(Na_{.048}Ca_{1.757}Mn_{.014}Fe^{2+}_{.181})_2(Fe^{2+}_{.456}Mg_{4.140}Ti_{.041}Al_{.363})_5(Al_{.520}Si_{7.480})_8$

Orthopyroxene composition. $X_{Mg}=0.78$

$(Na_{.001}Ca_{.014}Mn_{.009}Fe^{2+}_{.413}Mg_{.564})_{1.001}(Mg_{.969}Fe^{3+}_{.024}Ti_{.002}Al_{.005})_1(Al_{.031}Si_{1.969})_2$

Cited references that are not listed at the end of Trip P-4 in the guidebook:

Tracy, R.J.(1975)High grade metamorphic reactions and partial melting in pelitic schist, Quabbin Reservoir area, Massachusetts (Ph. D. Thesis). Contrib. # 20, Dept. of Geol. and Geog., Univ. of Mass., Amherst.

Shearer, C.S. (Ph.D Thesis, in preparation). Dept. of Geol. and Geog., Univ. of Mass., Amherst.

C-5

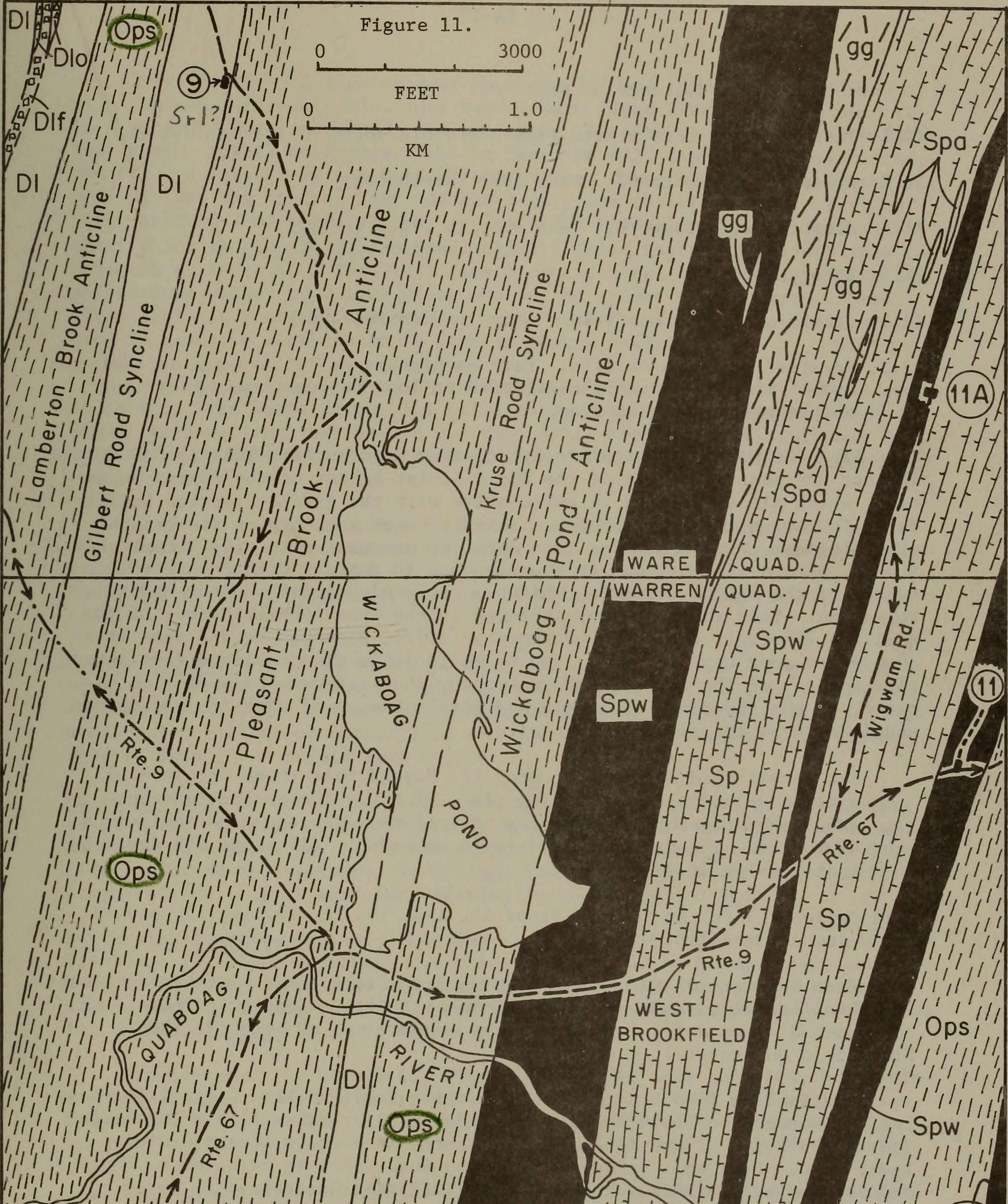


Figure 11.
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9
Lamberton Brook Anticline
Gilbert Road Syncline
Brook Anticline
Kruse Road Syncline
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WARREN
QUAD.
WICKABOAG
POND
Wickaboag
Pleasant
Rte. 9
Spw
Sp
Wigwam Rd.
11
Rte. 67
WEST
BROOKFIELD
QUABOAG
RIVER
10

Proceed short distance on Route 67.

20.1 Turn right at Mark's Auto Sales onto old Route 67 northeast-bound.

20.2 Re-enter new Route 67. Turn left (northeast)

21.4 Junction with Route 9. Take ramp to right (east).

21.5 Enter Route 9.

22.5 Center of West Brookfield. Bear left on Route 67.

23.3 Hereford Cow sign on left. Park on highway or in barnyard depending on number of vehicles. Proceed north on foot through, and along long northeast-trending outcrop.

Stop 11. (20 minutes approximately) (Warren Quadrangle) This is one of the largest and best exposures of the White Schist Member of the Paxton Formation, which all are agreed is correlative with the Middle Silurian Smalls Falls Formation in western Maine. This is based not only on its unusual mineralogical characteristics (see detailed discussion in Trip 4 text and Stop 4) but on its position in the sequence in contact with the Granulite Member of the Paxton Formation which is extremely similar to the Madrid Formation. This rock type was included in the Upper Schist Member of the Hamilton Reservoir Formation by Pomeroy (1977), although he did show it as a separate rock type locally. In the field it is distinguished from pyrrotite schists of the Partridge Formation by the extremely pale Mg-rich biotites, by the abundance of rutile and total absence of ilmenite and garnet, and locally by the presence of pyrite.

The formal road log ends at Stop 11. Beyond this there are several options depending on remaining time, if any. The remaining stops are linked together in a series of options with general descriptions of routes. Topographic maps are recommended. All stops are described individually at the end.

Full Option. This can include Stops 12, 12A, 13, 14, 15, 16, 17, and 18 but omits 11A and 11B.

East on Route 67 to center of North Brookfield, then east and northeast on School Street to southeast side of Tarbell Hill. Stop near Pecks Farm and descend slope a few feet below road to outcrops of Stop 12. (North Brookfield Quadrangle).

Continue on School Street to Hillsville Road. Follow Hillsville, Spencer and North Brookfield Roads east to Route 31 at Hillsville. Turn left (north) on Route 31 and follow through North Spencer to stream draining Eames Pond. Park near bridge on Nanigian Road which is parallel to Route 31 and descend into stream which is Stop 12A (Paxton Quadrangle).

Return west on Route 31 to North Spencer. Travel north on Rockland Road-Pleasant Dale Road to Route 122 and turn northwest. Follow Route 122 to Old Turnpike Road. To skip Stop 13 stay on Route 122. Follow Old Turnpike Road west to junction with Coldbrook Road. Stop 13 lies on Old Turnpike Road just west of junction (North Brookfield Quadrangle).

Drive north on Coldbrook Road to Route 122 and turn left (west). Turn right on old railroad grade, just beyond Ware River Bridge, then around to left onto Old Worcester Road. To skip Stop 14, stay on Route 122 into Barre. Turn north (right) on Granger Road at junction 822, then right again at junc-ion 861. About 0.1 mile beyond bottom of long downgrade look for steep driveway angling in from left and cliff in trees to left (west). Park on right about 0.2 mi south of road junction for Riverside Cemetery and walk to cliff which is Stop 14 (Barre Quadrangle). Drive north along river road to pavement at Route 62. Turn left (west) toward Barre. Eventually Route 62 passes deep valley of Prince River and begins ascent toward Barre. Take first left off Route 62 and park at south end of switchback to examine out-crop in trees to south which is Stop 15 (Barre Quadrangle).

Continue on same road which leads directly back into Route 62 and center of Barre. Take South Street 1.8 miles south past Quabbin Regional High School to powerline just beyond junction 873. Park and walk southeast 0.1 mile along powerline to large knob outcrop which is Stop 16 (Barre Quad-rangle).

Return to center of Barre on South Street and follow Route 122 north-west 0.1 mile to sharp southwest (left) turn. 0.1 mile beyond is clean out-crop in lawn on left. This is Stop 17 (Barre Quadrangle). Continue west on Route 122 to waist-high outcrop on right which is Stop 18 (Petersham Quad-rangle).

Oakham Option. Similar to Full Option but omits Stop 12A. From Stop 12 on School Street turn east on Hillsville Road to Mad Brook Road and thence to Oakham Road which becomes North Brookfield Road in Oakham. Turn left to-ward Oakham Village on Corner Road and north from Oakham on Cold Brook Road to Stop 13 to rejoin Full Option.

Barre Option. Direct route north from Stop 11 to Barre and graded bedding at Stop 16. Follows Route 67 through North Brookfield to Barre Plains and junction with Route 32. Take Route 32 west 0.5 mile to junction with South Street near Adams Cemetery. Turn right (northeast) on South Street and stay left (uphill) at next fork leading to powerline and Stop 16.

New Braintree-Barre Option. Includes stops 11A, 11B, then direct to Barre. From Stop 11 return southwest 0.4 miles on Route 67 to Wigwam Road. Sharp turn north onto Wigwam Road and travel north 1.0 mile to point where there is low outcrop on right and high outcrop on left. Powerline is 0.1 mile too far. This is Stop 11A (Ware Quadrangle).

Proceed north on Wigwam Rd. Stay straight at next junction, bear left at next two junctions and bear right onto West Brookfield Road at junction beyond New Braintree Town Line. Stop at small outcrop in bushes to right about 0.1 mile south of junction with Gilbertville Road. This is Stop 11B.

North on West Brookfield Road through center of New Braintree to right turn onto Barre Cut-off Road that leads direct to Route 67 and Barre Option.

Individual Stops

Stop 11A. (15 minutes approximately) (Ware quadrangle) This stop is along a contact between the Granulite Member of the Paxton Formation to the east, and the White Schist Member to the west which appears in a narrow belt interpreted as an isoclinal anticline. The best granulite is to be seen on the east sides of outcrops east of the road. The rocks are slabby and well layered on a scale of 2-3 cm. Although diopside-calcsilicate layers are subordinate, the purple biotite granulite usually has either labradorite or bytownite. The White Schist on the other side of the road is excessively rusty and abundant white mica looks like secondary muscovite, but it is in fact nearly pure Mg biotite.

Stop 11B. This stop is to examine the New Braintree olivine-hornblendite in the Wickaboag Pond anticline of Partridge Formation. The rock is described under Trip P-3, Stop 3A. In this region in Massachusetts ultramafic rocks seem to be confined to rocks of pre-Silurian age except for ultramafic bodies in the Belchertown pluton. However, the contact relations and origin of this body are very poorly known.

Stop 12. (15 minutes approximately) (North Brookfield Quadrangle). Gently west-dipping purple biotite granulite of the Paxton Formation on west limb of the Oakham anticline. Although calc-silicate rock is not abundant, the plagioclase in these granulites is usually labradorite or bytownite. Note pervasive but obscure E-W trending mineral lineation formed by elongate quartz and plagioclase grains. This is assigned to the backfold stage.

Stop 12A. (15-30 minutes) (Paxton Quadrangle) This locality was accidentally rediscovered by Tucker and Robinson on a late autumn evening in 1976. We think it is likely to be the type locality of the Paxton Schist of Emerson, because it is by far the largest natural exposure of the unit anywhere near Paxton. The rock consists of the same typical purple granulites with minor pegmatite and thin lenses of diopside calc-silicate. The section dips very gently and uniformly east on the east limb of the Gardner anticline. Foliation surfaces show both east-west (backfold stage) and northeast-trending (dome stage) linear fabrics. By climbing out of the gorge by the mill and walking north several hundred feet on a wood road it is possible to climb up through the Paxton Granulite Member and into the Paxton Quartzite and Rusty Schist Member capping a hill. This rock bears some similarity to an unnamed Silurian quartzite (Perry Mountain equivalent) described by Osberg (1980) on the Kennebec River, Maine which lies stratigraphically below the Fall Brook Formation that correlates with the Paxton Granulite Member. Our present interpretation is then that all or most of the "type section" is upside down! Return to cars by road beside gorge.

Stop 13. (10 minutes approximately) (North Brookfield Quadrangle) Low outcrop on north side of Old Turnpike Road is one of the few easily accessible outcrops of the pyrrhotite-sillimanite schists of the Partridge Formation in the core of the Oakham anticline. Specimens from Quabbin Tunnel (Tucker, 1977) show quartz-plagioclase-orthoclase-biotite-garnet-sillimanite± muscovite-graphite-pyrrhotite assemblages indicative of metamorphic Zone IV. One tunnel specimen from close to the Paxton contact on the west limb has all the characteristics of the White Schist Member, but could not be located

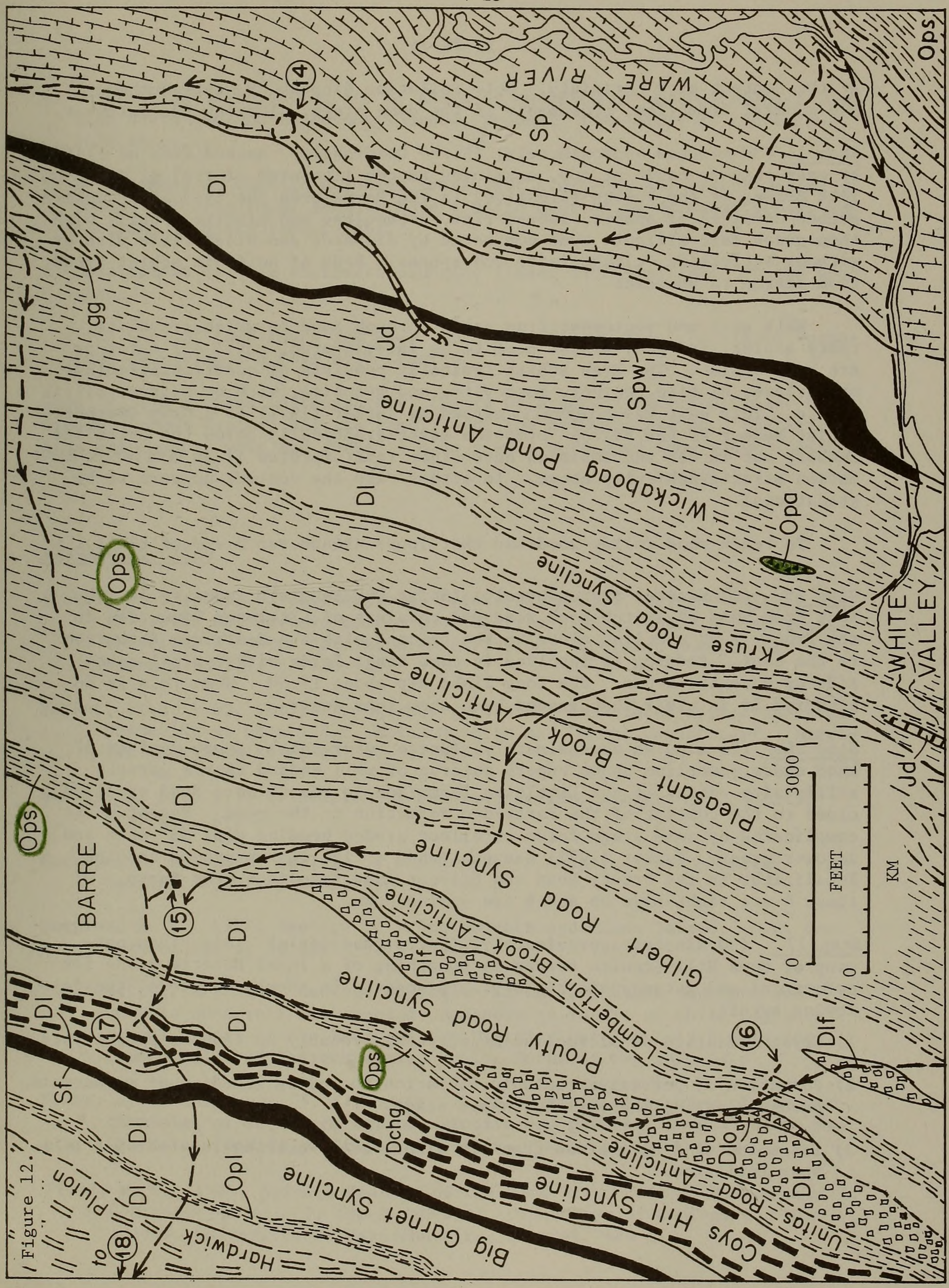
Pluton
to
18
Hardwick
Big Garnet Syncline
Coys Hill Syncline
Unitas Road Anticline
Prouty Road Syncline
Lamberton Brook Anticline
Gilbert Road Syncline
Pleasant Brook Anticline
Kruse Road Syncline
Wickaboag Pond Anticline
WARE RIVER
WHITE VALLEY
BARRE
Ops
Opl
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Figure 12.

at the contact with certainty. Note foliation dipping 7° west-southwest, and mineral lineation, presumably of the dome stage, plunging 6° southwest.

Stop 14. (30 minutes approximately) (Barre Quadrangle) Ascend face of cliff by easy ramp to cabin at top, examining superb exposures of typical Granulite Member of the Paxton Formation. In the Barre area the typical granulite member consists of quartz, labradorite, orthoclase and biotite usually with thin green calc-silicate beds dominated by diopside and plagioclase with or without actinolite, clinozoisite and sphene. Beds of sulfidic schist range from scarce to abundant.

Walk west and southwest from cabin through zone in which granulite, rusty schist, and gray schist seem to be interlayered, until all outcrops are gray schist. The gray schist typically consists of quartz, plagioclase, orthoclase, biotite, garnet, muscovite, and graphite, with or without sillimanite. This unit was originally mapped by Tucker (1977) as a Gray Graphite Schist Member of the Paxton Formation stratigraphically below the Granulite Member, but Tucker and Robinson have since reinterpreted it as Littleton Formation stratigraphically above. In either case the contact appears to be gradational.

To reach road follow woodroad that loops around south end of cliff.

Stop 15. (15 minutes approximately) (Barre Quadrangle) Exposure is 100 feet from bend of switch-back road and consists of Littleton Formation in the Prouty Road syncline close to the contact with the Partridge Formation to the east. Bedding is involved in dome stage folds with typical east-side-up movement sense. The long limbs dip about 12 NW. When this is deciphered it is clear that graded beds show tops west.

Stop 16. (25 minutes approximately) (Barre Quadrangle) Upper surface of knob under powerline shows superb outcrop of well bedded coarse garnet-sillimanite schist of the Littleton Formation in the Gilbert Road syncline, close to the contact of the Partridge Formation to the west. Except where complicated by dome stage folds excellent graded bedding dips 33° west and is overturned. Tucker (1977) has published a list of ten graded bedding localitites in the Prouty Road and Gilbert Road synclines near Barre. Of these 4 are right-side up and 6 are upside down.

Stop 17. (20 minutes approximately) (Barre Quadrangle) This clean outcrop of Coys Hill Granite serves as something of a local Rosetta Stone for structural and metamorphic history. It appears to show evidence of the following events:

1) Crystallization of microcline megacrysts, probably as igneous phenocrysts.

2) Formation of pervasive tectonic foliation including rounding of megacrysts, probably during the regional nappe stage.

3) Intrusion of fine-grained granitic dikes, cross-cutting the tectonic feldspar foliation.

4) Deformation of foliation and of dikes by conspicuous west-plunging folds, with south over north movement sense, probably from early in the back-fold stage.

5) Development of ductile mylonite zones that cross-cut the west-plunging folds. Locally these seem to have a north over south movement sense, and a strong down-dip linear fabric.

6) Development of weak southwest-plunging linear fabric assigned to the dome stage.

At back of lawn there are small outcrops of big garnet Littleton Formation overlying the Coys Hill Granite.

Stop 18. (10 minutes approximately) (Barre Quadrangle) Excellent waist-high exposure shows typical biotite tonalite of the Hardwick pluton. Foliation dips very gently west and there is also a well developed dome stage lineation.

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