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# Lithofacies, Stratigraphy and Structure in the Rocks of the Connecticut Valley Trough, Eastern Vermont

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# LITHOFACIES, STRATIGRAPHY, AND STRUCTURE IN THE ROCKS OF THE CONNECTICUT VALLEY TROUGH, EASTERN VERMONT

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Cady (1960) referred to the large area in eastern Vermont of primarily gray metasedimentary rocks bounded by the Taconic unconformity on the west and the Monroe line on the east as the Connecticut Valley-Gaspe synclinorium. This belt of rocks extends northeast from Vermont across southeastern Quebec and out to the end of the Gaspe Peninsula (Williams, 1978). To the south, it extends across western Massachusetts (Zen and others, 1983) and western Connecticut (Hatch and Stanley, 1973; Rodgers, 1985) to Long Island Sound. The emphasis on this trip is on these rocks as a sedimentary sequence. The stratigraphic data that I will show suggest that, at least in this area, the structure of the rocks in this belt is better interpreted as anticlinal. The belt herein will be referred to as the Connecticut Valley trough.

The rocks of the trough are gray slates, phyllites, schists, micaceous quartzites, and punky brown-weathering quartzose marbles. Metavolcanic rocks, primarily the Standing Pond Volcanics, constitute no more than a few percent of the total section. Because the formations that have been mapped in this package of rocks consist of different proportions of the same metasedimentary lithologies, the Connecticut Valley trough has long been considered to consist of one closely related sedimentary sequence. Since publication of the Centennial Geologic Map of Vermont (Doll and others, 1961), this sequence has been widely accepted as Late Silurian to Early Devonian in age.

Recent discoveries in rocks of the sequence of Middle to Late Ordovician graptolites in southern Quebec (Bothner and Berry, 1985) and southeast of Montpelier, Vermont, (Bothner and Finney, 1986), and of Early Devonian plants (Francis Hueber, Smithsonian Institution, written commun., October 5, 1985) in southern Quebec have raised questions about the age of the rocks and whether they do indeed represent one coherent stratigraphic sequence. This field trip will not resolve the question of the age(s) of the rocks, but it should shed some light on whether or not, or to what extent, they can reasonably be considered to form one continuous sedimentary sequence.

The most recent published compilation of the rocks of the Connecticut Valley trough in Vermont is that of Doll and others (1961). On their map, the rocks of the trough are divided into three formations--the Northfield, the Waits River, and the Gile Mountain. A slightly simplified version of their map of these rocks is shown here as figure 1. The present field trip is one outcome of a project to restudy the depositional history of the rocks in the area of the figure. These rocks probably were deposited at or somewhere near the eastern margin of North America during the time interval between the Taconian and Acadian orogenies. Tentative conclusions of this restudy, which will be pointed out and discussed on the trip, include (1) reassignment of the

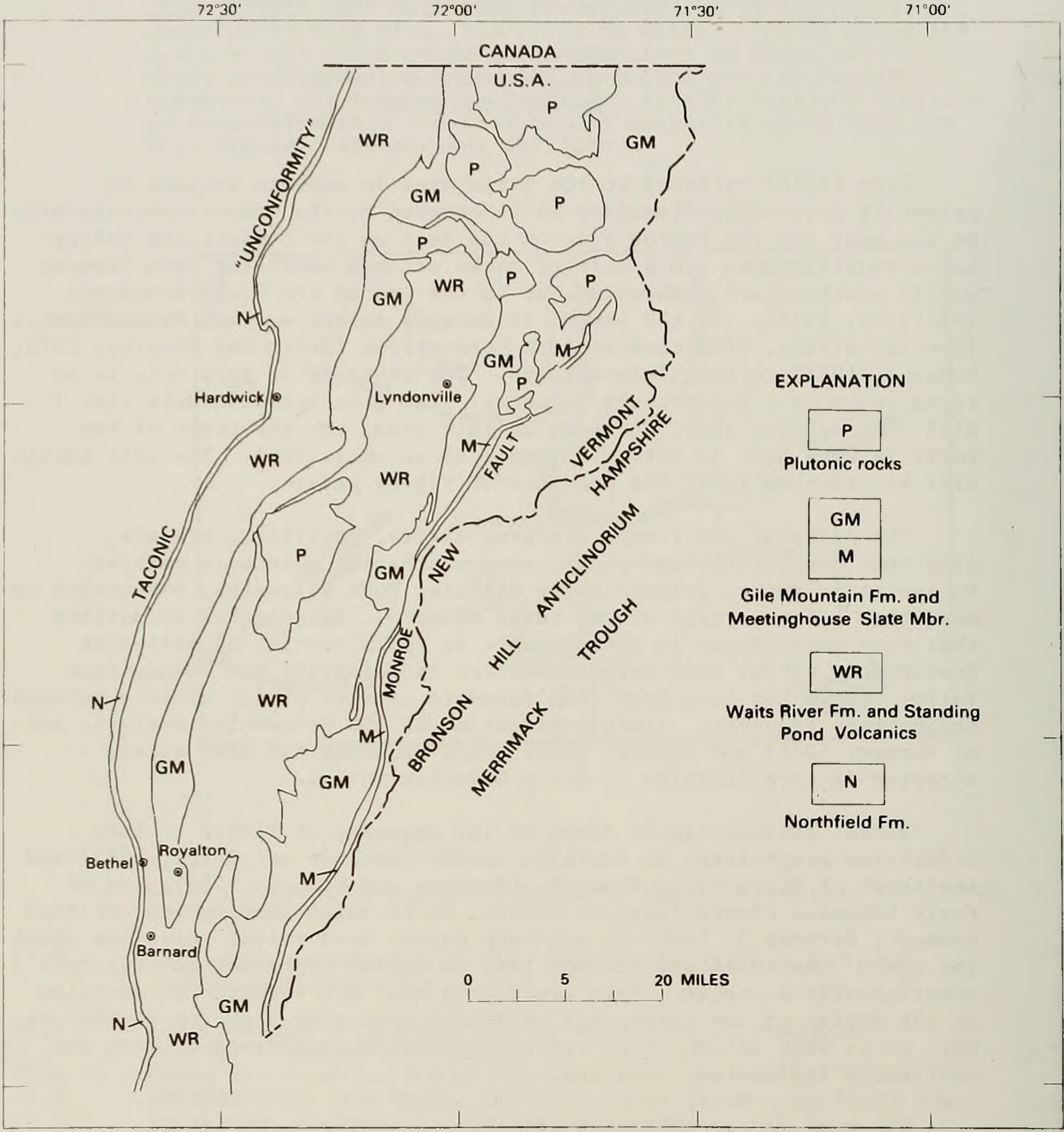


Figure 1. Geologic map of the metasedimentary rocks of the Connecticut Valley trough of eastern Vermont north of about 43°30′, modified slightly from Doll and others (1961).

Northfield Formation to a position above, rather than below, the Waits River Formation and consequent correlation of the Northfield with the Gile Mountain, (2) recognition of at least three mappable lithofacies within rocks previously mapped as undifferentiated Gile Mountain Formation, (3) reinterpretation of the overall structure of the sequence as something more closely approximating an anticlinorium than a synclinorium, (4) a possible sedimentary model for the observed lithofacies that suggests an easterly source for the sediments of the sequence, and (5) some structural complexities that result from that sedimentary model.

As noted above, the commonly accepted concept of the stratigraphy of the Connecticut Valley trough (Doll and others, 1961) divides the rocks into three formations. The Northfield Formation forms a narrow belt about 1/2 mile wide along the western margin of the trough (fig. 1) and is interpreted by Doll and others (1961) as forming the basal unit of the sequence. They described the Northfield as consisting of "dark gray to black quartz-sericite slate or phyllite with fairly widely spaced interbeds a few inches thick of siltstone and silty crystalline limestone...". They showed the Waits River Formation on their map explanation as being stratigraphically equivalent to the Gile Mountain, but, on their cross sections, it appears as stratigraphically below the Gile Mountain. The Waits River consists of dark-gray slate, phyllite, or schist similar to that of the Northfield, interbedded with "gray quartzose and micaceous crystalline limestone weathered to a distinctive brown, earthy crust" (Doll and others, 1961). This latter rock is widely known to Vermont geologists as "the punky brown". At or near the top of the Waits River is the Standing Pond Volcanic Member which consists of a few hundred feet of amphibolite and greenstone. The third formation of Doll and others (1961) in the trough sequence is the Gile Mountain Formation. It, too, contains dark-gray phyllite or schist, characteristically interbedded with light-gray micaceous quartzite. Minor beds of brown-weathering crystalline limestone (marble) may be present. Approximately the easternmost 1/2 to 1 mile of the Gile Mountain was distinguished by Doll and others (1961) as the Meetinghouse Slate Member, consisting of "gray slate or phyllite characterized by beds of gray schistose quartzite 1/8 inch to 3 inches thick". The Meetinghouse was interpreted by them as forming the basal unit of the Connecticut Valley sequence along the eastern margin of the trough (the Monroe line) and thus to be approximately correlative with the lithically similar Northfield Formation along the western margin of the trough. The marginal surfaces of the trough, the Taconic unconformity on the west and the Monroe line on the east, were interpreted by Doll and others (1961) as unconformities. Note, however, that all of the quadrangle reports (Eric and Dennis, 1958: Hall, 1959; White and Billings, 1951; Hadley, 1950; Doll, 1944; Lyons, 1955) along the Monroe line from which Doll and others (1961) compiled their map interpreted the "Monroe line" as a fault and placed the Meetinghouse above, rather than below, the main body of the Gile Mountain.

Figure 1 shows that Doll and others (1961) have mapped two north-south belts of both the Waits River and the Gile Mountain Formations. The two belts of the Waits River join in the southern part of figure 1 at the south end of what Doll and others (1961, cross section C-C′) show as the Townshend-Brownington syncline. Fisher and Karabinos (1980) and I (fig. 2) have since reconfirmed from graded beds the correlation of the two belts of the Waits River and the structural nature of this syncline, which plunges gently north in this area. Figure 1 also shows that the two belts of Gile Mountain Formation come together at the north end of the figure. The abundance of intrusive rocks in this area tends to obscure stratigraphic relations, but previous detailed mapping and my own reconnaissance indicate that the eastern belt of Waits River does terminate northward, approximately as shown. This asymmetric distribution of formations east to west across the trough required Doll and others (1961, cross sections) to pinch out the Waits River Formation eastward between its eastern outcrop belt and the Monroe line.

Reconnaissance mapping in part of this area has shown that these rocks can be subdivided further. One of the major objectives of the trip will be to demonstrate the newly differentiated lithofacies of the Gile Mountain and to discuss what they may mean in terms of depositional environment, stratigraphic sequence, and the implications to structural interpretations. The following discussion, as well as the field trip, will progress from west to east across the trough.

The Northfield Formation, to be seen at STOP 1, forms a narrow belt along the western margin of the mapped area (figs. 1, 2). Although primarily dark-gray, aluminous, graphitic phyllite (or slate or schist, depending on metamorphic grade) and minor brown-weathering marble beds, the Northfield locally contains beds of light-gray, fine-grained micaceous quartzite as much as a few inches thick that generally are sharply bounded on one side but grade on the other side into dark-gray phyllite. The thickness and grading style of these graded beds markedly resemble those of the graded beds of the western belt of the Gile Mountain (described below). Furthermore, at the localities where graded beds were seen in the Northfield near the contact with the Waits River, those graded beds all indicate that the Northfield overlies the Waits River, contrary to the traditional view that the Northfield is stratigraphically beneath the Waits River. Some of those graded beds will be seen at STOP 1. If the Northfield is indeed stratigraphically above the adjoining Waits River, then it is in the same stratigraphic position as the Gile Mountain Formation as discussed below. It is hoped that STOPS 1 and 2 will demonstrate the similarities between these two units.

East of the Northfield is the westernmost of the two belts of Waits River Formation. The contact between the two formations is gradational through an interval of as much as a few hundred yards by eastward increase in the number and thickness of brown-weathering quartzose micaceous marble beds in a matrix of dark-gray aluminous phyllite. This contact will be seen at STOP 1. In this western belt of Waits River, these marble beds are 1 to 30 feet thick and constitute about 15 to 30 percent of the formation. Graded or ungraded beds of quartzite are very rare in this unit.

In the middle of this western belt of Waits River is a narrow belt of dark-gray phyllite with only minor beds of marble but with scattered beds of graded micaceous quartzite. It is shown on figure 2 as a belt

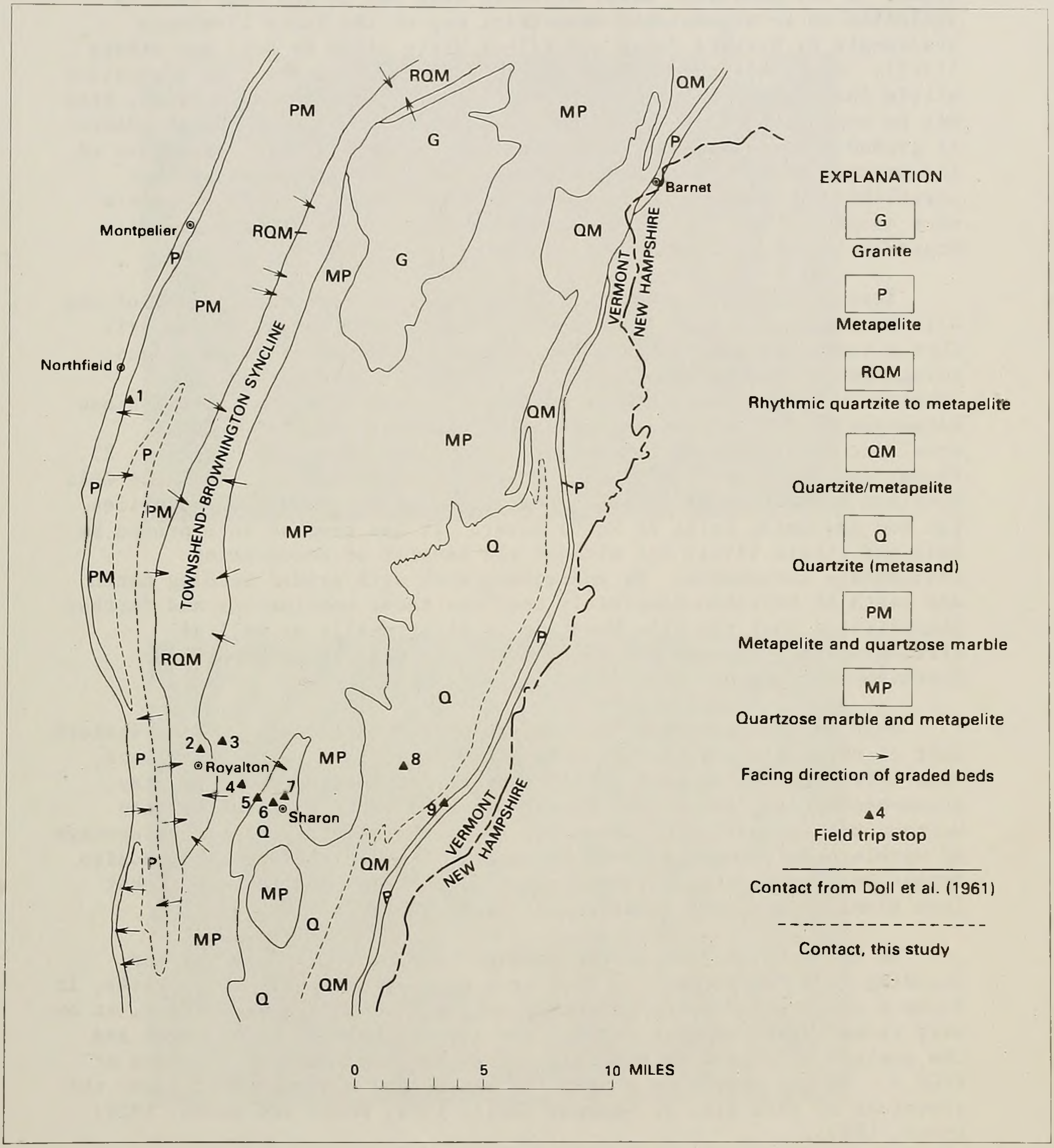


Figure 2. Geologic map of part of the area of figure 1 showing the lithic subdivisions of the present study.

of "metapelite" facies 2 miles west of Royalton. This belt does not appear on any published maps, although what may be the same belt is indicated on an unpublished manuscript map of the Barre 15-minute quadrangle by Richard Jahns and Walter White cited by Doll and others (1961). Available graded beds suggest that these rocks form a syncline within the broader belt of Waits River Formation (fig. 2). If so, they may be another belt of Gile Mountain correlative rocks. The abundance of graded beds intermediate between that of the Northfield and that of the western belt of Gile Mountain is at least compatible with that correlation, although the fact that brown-weathering marble beds are more abundant here than in either the Northfield or the western Gile Mountain is not as readily explained.

East of the western belt of Waits River is the western belt of the Gile Mountain, which will be seen at STOP 2. The rocks of this belt form a very distinctive unit, the structural potential of which was recognized by Fisher and Karabinos (1980). It consists of thin (generally 2-6 inches), almost universally graded beds of fine-grained micaceous quartzite and gray phyllite or schist (fig. 3). In an excellent detailed study of a small area around Royalton (figs. 1, 2), Fisher and Karabinos (1980) demonstrated from graded beds that the Gile Mountain Formation (at least in that area) stratigraphically overlies the two adjoining belts of Waits River. It had been so interpreted by Doll and others (1961) but without the benefit of documenting sedimentary structures. My subsequent work with graded bedding north and south of Royalton completely confirms those conclusions and further demonstrates that the Gile Mountain is structurally as well as stratigraphically above the Waits River (fig. 2) --the Townshend-Brownington syncline is alive, well, and real.

Next to the east from the western Gile Mountain belt is the eastern belt of Waits River Formation. As with the western Waits River belt, this belt consists of gray phyllite or schist interbedded with gray, brown-weathering, quartzose, micaceous marble. It differs from the western belt primarily in appearing to have a slightly higher percentage of marble beds (commonly 50-80 percent). The interbedded schists also appear to contain significantly more quartz veins and to be somewhat less aluminous. These rocks will be seen at STOPS 3 and 4.

At the east contact of the eastern belt of Waits River is the Standing Pond Volcanics. In this area of gray metasedimentary rocks, it forms a distinctive unit, generally only a few hundred feet thick, at or very close to the contact between the eastern belt of Waits River and the eastern belt of Gile Mountain. The Standing Pond will be seen at STOP 5. It has served as a critical marker horizon for working out the structure of this part of Vermont (Doll, 1944; White and Jahns, 1950; Lyons, 1955).

To the east of the Standing Pond is the eastern belt of the Gile Mountain Formation (fig. 1). Although the lithologies of the eastern and western belts of the Gile Mountain have only recently been differentiated (Hatch, 1986), they differ quite markedly, particularly south of about 44° latitude. In this part of the State, I have subdivided the eastern Gile Mountain into two distinct lithofacies (fig.

A

B

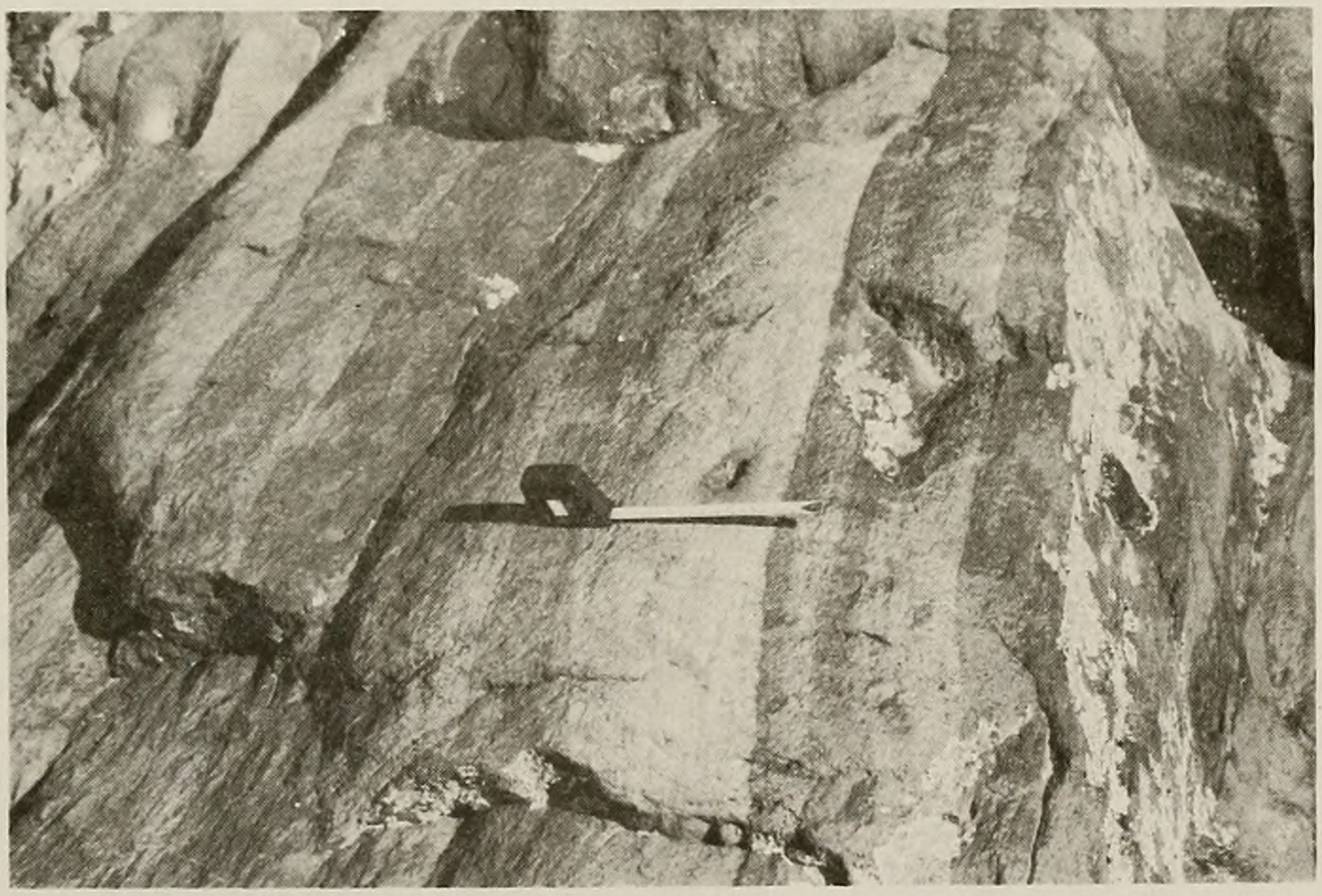

Figure 3. Photographs of the rhythmically graded facies of the western belt of the Gile Mountain Formation. A, View looking north at exposure near the south end of the Brownington syncline. Graded beds top to the east (right). B, Exposure at STOP 2. Graded beds top to the left.

2), which will be seen at STOPS 6,7,8,and 9. The western part of the eastern Gile Mountain belt consists of thick (up to 30 feet) beds of micaceous quartzite and quartz-feldspar-mica schist (fig. 4). These rocks, particularly the schists, have a brownish cast in outcrop or hand specimen and contain no visible graphite, in contrast to the gray graphite-bearing schist beds of the western Gile Mountain. Furthermore, graded bedding is very rare in these rocks, which I interpret to be metamorphosed, relatively rapidly deposited sands and muddy sands. They contrast to the more slowly deposited rhythmically graded rocks of the western belt, which I interpret to be metamorphosed turbidites.

The eastern part of the eastern belt of Gile Mountain is underlain by what is designated the quartzite/metapelite facies in figure 2. These rocks are distinctly different from the rocks of the quartzite facies to the west (fig. 2) and, in some, but not all, ways, resemble the rocks of the rhythmically graded facies of the western Gile Mountain. The quartzite-metapelite facies rocks are fine-grained, light-gray micaceous quartzite and dark-gray, aluminous, graphitic phyllite. Beds generally range in thickness from a fraction of an inch to about a foot (fig. 5), and show much local variation in contrast to the more consistent bedding thickness of the rhythmically graded facies to the west (compare figs. 5 and 3). The quartzite/metapelite facies rocks are believed to have formed as slowly deposited fine to very fine grained silt and clay-sized sediment. Approximately the easternmost 1/2 to 1 mile of this facies is predominantly, and in some exposures exclusively, dark-gray phyllite or slate. These rocks were mapped by Doll and others (1961) and by the quadrangle mappers from whom they compiled as the Meetinghouse Slate Member of the Gile Mountain Formation. Although all of the quadrangle reports from which Doll and others (1961) compiled their map placed the Meetinghouse at the top of the Gile Mountain, they placed it at the bottom. Neither group published any hard data on which to base their interpretation. My own work has turned up abundant evidence for isoclinal folding in these rocks, but a slight majority of graded beds near the gradational western contact of the Meetinghouse suggests that the Meetinghouse may lie stratigraphically at the top, rather than at the bottom, of the Gile Mountain. The rocks of this eastern part of the eastern belt of the Gile Mountain and the Meetinghouse will be seen at STOP 9.

Figure 6 is a reinterpreted cross section across the trough. It differs from the cross sections of Doll and others (1961) in a number of ways. First, for the reasons cited by Hatch (1985) and by Westerman (1985), as well as the stratigraphic topping data cited here, both boundaries of the trough are shown as faults. Second, not only the Northfield, but also the narrow belt of Northfield-like rocks in the middle of the western belt of Waits River are shown on figure 6 as stratigraphically above the Waits River and stratigraphically equivalent to the Gile Mountain. Third, the resulting configuration (fig. 6), as noted above, is more that of an anticlinorium than a synclinorium.

Figure 7 is an attempt to arrange the facies of the rocks in figure 6 into a depositional model. The distribution of coarse- and fine-grained rocks in figure 7 suggests an easterly source region, particularly for the Gile Mountain and correlative rocks. I further suggest that the apparent higher quartz content in the carbonate-quartz

Figure 4. Photograph of the thick-bedded micaceous quartzite facies of the Gile Mountain in the western part of the eastern belt. Pencil is about 6 inches long.

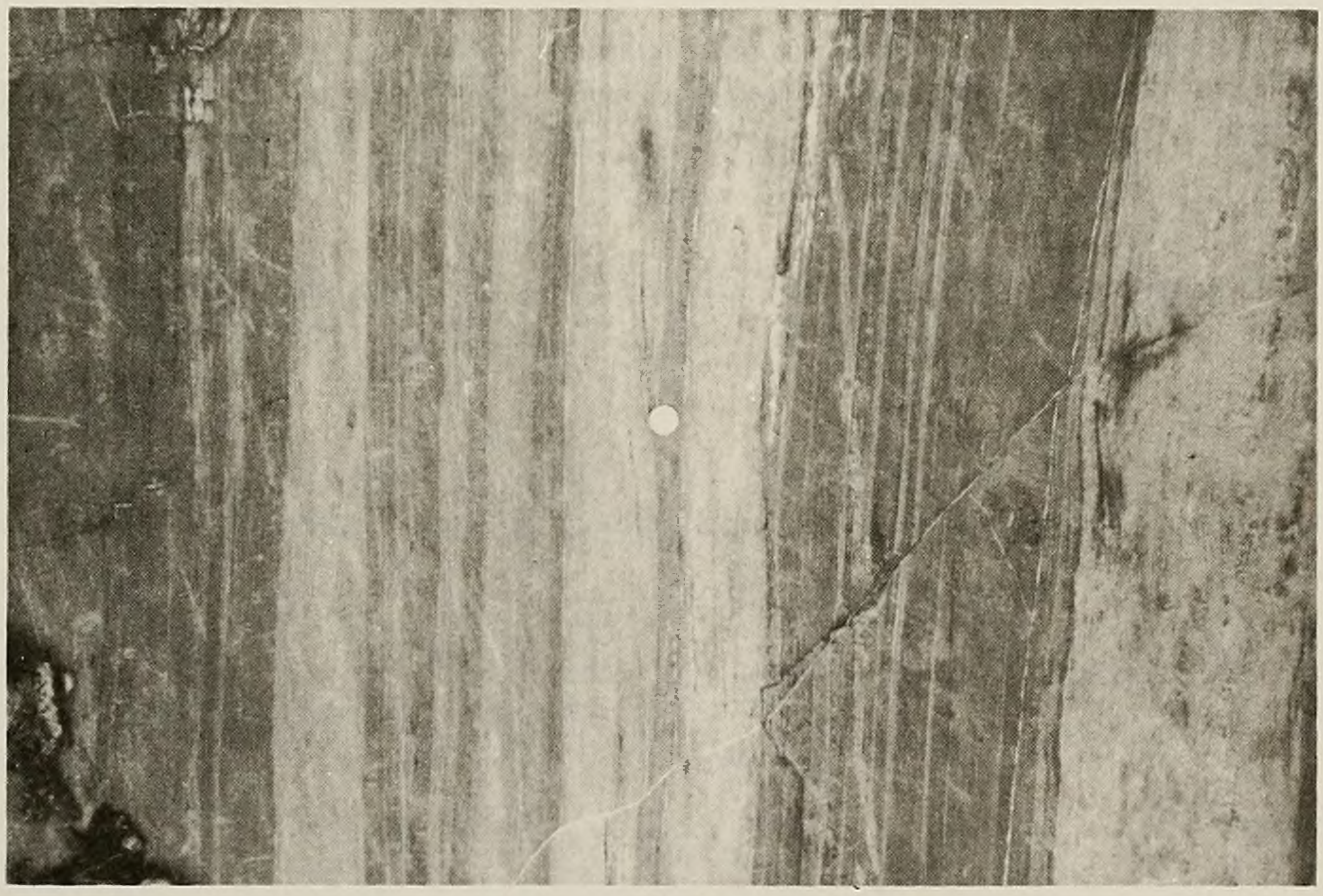

Figure 5. Photograph of the quartzite/metapelite facies of the eastern part of the eastern belt of the Gile Mountain. From cut on Route I-93 about 5 miles northeast of Barnet, Vermont. Coin is about one inch across.

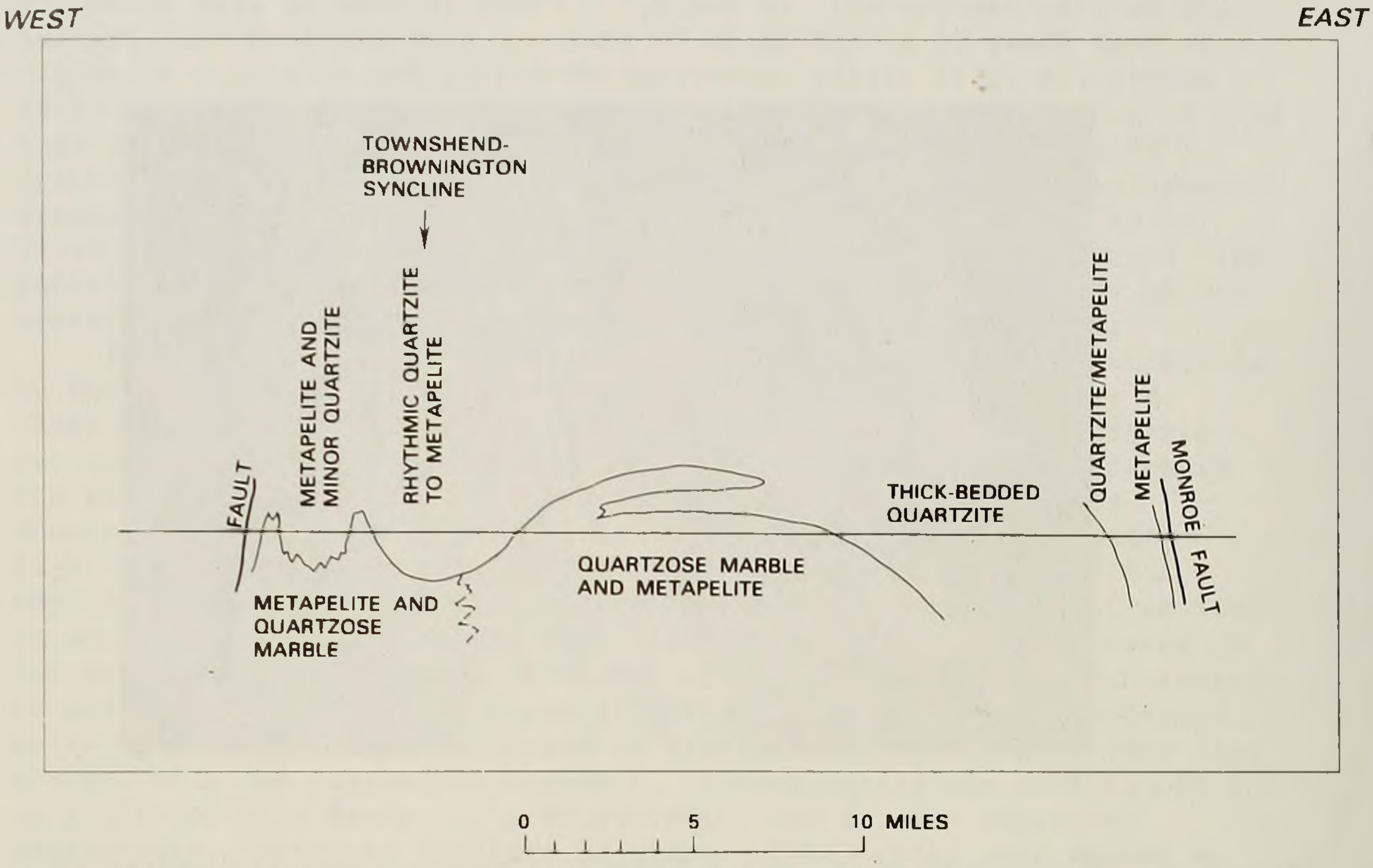


Figure 6. Cross section across the Connecticut Valley trough at about 44° showing proposed revised stratigraphic-structural model.

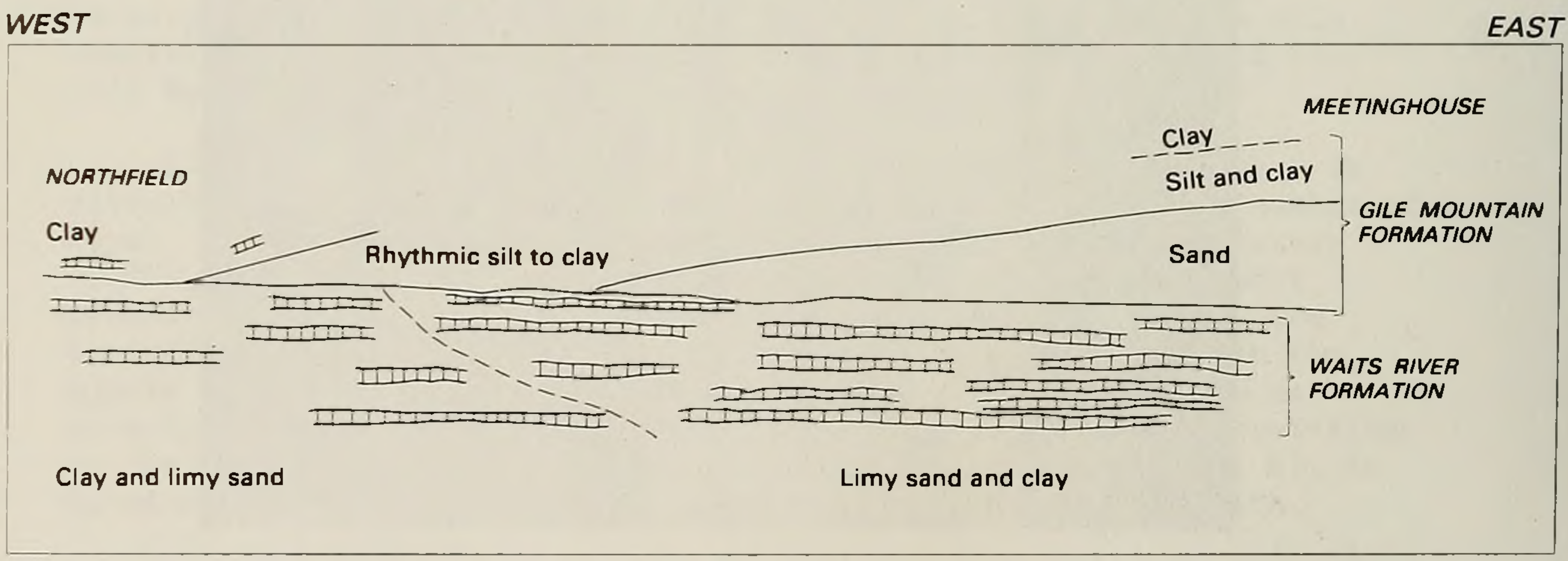


Figure 7. Unfolded and unmetamorphosed restoration of the cross section shown in figure 6.

sands of the eastern belt of Waits River and the lower alumina content of the shales of the eastern Waits River relative to the western Waits River rocks also could be interpreted to indicate an eastern source. The significance of the higher percentage of carbonate sands in the eastern Waits River is questionable, but the observed relations seem at least compatible with an eastern derivation.

Lengthy speculation about the exact location of this easterly source region for the Connecticut Valley trough sediments is beyond the realm of this guidebook article. Suffice it to say, however, that regardless of the exact age(s) of the trough rocks, if they are indeed post-Taconian and pre-Acadian, the presence of Early and Late Silurian and Early Devonian strata on the Bronson Hill anticlinorium severely constrains the times during which the Bronson Hill could be a source. Furthermore, the Bronson Hill contains no presently exposed or known source rock for the carbonate sands of the Waits River. And finally, present ideas on the Merrimack trough east of the Bronson Hill indicate that it was receiving sediment from a western source from the Late Ordovician on into the Silurian (Moench, 1969; Hatch, Moench,and Lyons, 1983). Whatever the answer to the question of the source area of the Connecticut Valley trough rocks, it is not simple.

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## ROAD LOG FOR TRIP B-3

Pertinent maps:
- Topo maps, 7.5-minute scale, in order of the trip:
  - Northfield
  - Roxbury
  - Randolph
  - Bethel
  - South Royalton
  - Sharon
  - South Strafford
- Geologic maps:
  - Doll and others (1961) (State map)
  - Ern (1963) (Randolph 15-minute quadrangle)
  - Doll (1944) (Strafford 15-minute quadrangle)

The trip will assemble in the Norwich University (Northfield) parking lot immediately south of the Cabot Science Building. Because parking is limited at most of the trip stops, PLEASE consolidate into as few vehicles as possible. The trip will return to the parking lot at the end of the day.

LUNCHES: Bring a lunch or makings therefor. We do not plan to stop at any eatery or store.

A few stops will involve moderate walks along roads, but no strenuous traverses are planned.

The total trip will involve about 100 miles round trip, so drivers should please be sure to have sufficient gasoline before starting out.

Mileage

00.0 Norwich University parking lot.
From parking lot turn right (south) onto Route 12.

00.1 Bear left on Route 12 at junction with Route 12a.

01.3 Intersection of Route 12 with brand new (post map) section of Route 64. Park on right shoulder of Route 12.

STOP 1 (Roxbury 7.5-minute quadrangle)

We will examine the new cuts at the intersection and east along new Route 64. At the intersection, the exposed rocks are typical of the Northfield Formation. The rock is medium-dark-gray, slaty, graphitic, aluminous phyllite, here at biotite grade. Although bedding is difficult to see on the fresh surfaces of the cut, the glacially polished surface on the top of the exposure shows a few beds an inch or so thick of lighter gray rock. This lighter gray rock is richer in quartz and poorer in micas and graphite than the darker phyllite and is interpreted to represent original silt-rich beds within the sequence of clay-sized sediment. The gradational and sharp boundaries of these beds of originally coarser (relative to clay) silt are interpreted to reflect graded bedding from which primary stratigraphic tops can be determined. A few thin (2- to 6-inch) beds of brown-weathering quartzose marble ("punky brown" of local jargon) are present.

To the east, up new Route 64, the rock is predominantly the same medium-dark-gray phyllite with local thin beds of lighter gray metasilt. Approximately 3,000 feet east of Rte. 12 the punky brown-weathering quartzose marble beds have increased gradually in number and thickness. Here they are as much as 3 feet thick and form about 10 percent or more of the section. Previous mappers (Richard Jahns and Walter White, unpublished manuscript map) and I call these rocks the Waits River Formation. The boundary between the Waits River and the Northfield is somewhere in the long cut through which we have just walked. It is clearly gradational by progressive eastward increase in quartzose marble in a sequence dominated by Northfield-type phyllite. The bedding style and the characteristic punky brown weathering of the quartzose marble beds can be seen best on the top surface of the very eastern end of the cut. These rocks characterize the western belt of the Waits River Formation, at least between Barnard and Hardwick. This will be our only formal stop in this belt. Although faint graded beds face both east and west through the long cut containing the Northfield-Waits River contact, those observed closest to the contact face west. If correctly interpreted, these tops suggest that the Northfield is stratigraphically above the Waits River, the opposite relation to that presented by Doll and others (1961) and all previous reports. Graded beds near the Northfield-Waits River contact to the south near Bethel (fig. 1) also suggest that the Northfield stratigraphically overlies the Waits River (fig. 2) (Hatch, 1986). Keep these relations and the faint graded beds in the Northfield in mind when we look at the rocks of the Gile Mountain Formation at Stop 2.

A second cleavage that strikes about N25$^{\circ}$E and dips about 45$^{\circ}$NW is locally well developed and is axial planar to relatively open folds that fold both bedding and earlier schistosity. The earlier schistosity can be locally demonstrated to be axial planar to isoclinal folds in bedding.

Cubes of pyrite about 1/2 inch across are abundant in a narrow zone about 3,900 feet east of Route 12. I have noted them elsewhere at about the same distance from the western margin of the trough. Their unfractured and undeformed character suggests that they formed relatively late, after development of the folds and cleavages. One interesting possibility is that they might be related to Mesozoic faulting.

Return to the cars and continue south on Route 12.

05.5 Parking area for Baker Pond boat access on the right.

05.7 Route 65 enters from left. Continue straight on Route 12.

11.0 Village of East Braintree.

16.3 Junction with Route 12A in Randolph Village. Bear left on Route 12 through village.

23.8 Follow Route 12 through Bethel Village.

24.4 At east end of Bethel Village, leave Route 12, which turns right to cross the White River, and continue straight ahead (southeast) on Route 7 EAST which came in from the right.

25.9 Troop E of Vermont State Police on right.

27.2 Pass <u>under</u> Route I-89.

27.9 Junction with Route 14. Turn right on Route 14.

28.6 Pass <u>under</u> railroad bridge.

29.4 Village of Royalton.

29.9 Pass under railroad bridge again.

30.4 Park in parking areas on right.

<u>STOP 2</u> (South Royalton 7.5-minute quadrangle)

Outcrops are in the White River just south of the road. The rocks are very well bedded interbedded gray graphitic phyllite or schist and light-gray, fine-grained micaceous quartzite in roughly equal proportions (fig. 3). Most beds are graded in the same manner as those at Stop 1. These rocks were mapped by Ern (1963) and by Doll and others (1961) as the westernmost of the two belts of Gile Mountain Formation (fig. 1). This exposure and others in the immediate area provided the evidence upon which Fisher and Karabinos (1980) based their conclusion that this belt of Gile Mountain Formation stratigraphically overlies the Waits River Formation that bounds it to the east and west. As a result of two periods of folding, beds face both east and west in the exposures at this stop, but numerous excellent exposures along both contacts of this belt to the north and south between Barnard and southeast of Montpelier (fig. 2) all support the interpretation of Fisher and Karabinos (1980). Abundant structural data further indicate that the belt forms both a structural and a stratigraphic syncline.

If my reading of the graded beds near the Northfield-Waits River contact at Stop 1 and other locations is correct, the Northfield is correlative with the rocks here at this stop. I suggest that the faintly graded phyllite and quartzite at Stop 1 are a (slightly lower grade) more distal facies equivalent of the rocks we are standing on here.

Return to the cars and continue east on Route 14.

31.4 Turn left (north) onto Route 110 toward Tunbridge and Chelsea.

31.9 Park on right shoulder of road.

STOP 3 (South Royalton 7.5-minute quadrangle)

Cuts on both sides of the road are in the eastern belt of the Waits River Formation, east of the Gile Mountain rocks at Stop 2.

The rocks here are punky-brown-weathering quartzose marble, in beds as much as 10 feet thick, and graphitic quartz-mica phyllitic schist. Thick beds of schist commonly contain beds of marble 2 to 4 inches thick. Quartz veins averaging 2 inches in width and 1 or 2 feet in length are common and characteristic of the eastern belt of Waits River. Compare the rocks here with the rocks at the eastern end of Stop 1, particularly in terms of protolith and possible facies relations. Also note that these rocks, as is almost universally true throughout this eastern belt of Waits River, appear to be much more complexly deformed than the rocks to the west. To what extent is this apparent greater (more complex) deformation the result of more intense or complex folding and metamorphism and to what extent does it result from the greater ability, or propensity, of the carbonate rocks here to flow during deformation? I favor some of both.

Return to the cars and continue north on Route 110.

32.1 Turn left onto a narrow paved road that goes back south parallel to Route 110.

32.4 Rejoin Route 110 and go south.

32.8 Turn left (southeast) onto Route 14 South.

34.3 Park in parking area on right.

STOP 4 (South Royalton 7.5-minute quadrangle)

Outcrops of the eastern belt of the Waits River Formation are in the White River on the right.

The rocks here are gray, graphitic, medium-grained phyllitic mica schist and gray quartzose marble in beds 3 to 10 feet thick. The schist contains many quartz veins. The marble beds are not only complexly folded, but individual beds change in thickness along strike, suggesting flowage during deformation. Although the Waits River rocks at Stop 1 showed two periods of folding and cleavage, the deformation here seems more complex and intense than in the western belt. Note also the rusty coating on the schists, which seems to characterize the Waits River schists (particularly of the eastern belt) in contrast to the much less rusty, lithically similar schists of the Gile Mountain.

Return to the cars and continue southeast on Route 14.

35.2 Town line, enter Sharon.

35.9 Park in parking area on the right.

STOP 5 (Sharon 7.5-minute quadrangle)

Walk ahead (southeast) down Route 14 about 1,300 feet to a point just east of a small brook crossing under the road and go right to outcrops in the White River.

The rock here is dark-gray-green amphibolite assigned to the Standing Pond Volcanics by Doll (1944) and Doll and others (1961). This unit, which is generally only a few hundred feet thick, has played a key role in working out the structure of this part of Vermont (Doll, 1944; White and Jahns, 1950; Lyons, 1955). It is interpreted to be a metamorphosed mafic tuff and, thus, should represent a time surface in the midst of the metasedimentary pile. In this area, it occurs at or very close to the contact between the eastern Waits River and the eastern Gile Mountain, although it has been mapped locally at a significant distance from it (see, for example, Doll, 1944; Lyons, 1955), suggesting that the metasedimentary unit boundaries are at least locally time transgressive.

Return to the cars and continue southeast on Route 14.

36.8 Park on the right shoulder on the grass under or immediately east of Route I-89.

STOP 6 (Sharon 7.5-minute quadrangle)

Walk back to outcrops in the White River about 600 feet northwest of Route I-89.

The rocks here are distinctly brownish-gray quartz-feldspar-biotite-garnet micaceous quartzites and schists. A few beds of punky-brown-weathering quartzose marble are as much as 3 feet thick. These rocks were mapped by Doll (1944) and Doll and others (1961) as Gile Mountain Formation. Although definitive graded beds were not seen in the exposures along the White River, graded beds a few miles to the north (fig. 2) do suggest that these rocks are stratigraphically above the Standing Pond, in agreement with the traditional view.

Note, however, the differences between these rocks and the rocks of the western belt of Gile Mountain at Stop 2. Here, the sand to shale (quartzite to schist) ratio is significantly higher; the quartzite beds are much thicker; the rocks are more feldspathic; the schists contain much less, if any, graphite; the biotite content is much higher; and the overall aspect of the rocks is brown rather than gray. Yet the available structural and graded bed evidence indicates that both the rocks at Stop 2 and the rocks here stratigraphically and structurally overlie the intervening belt of Waits River. Note also that punky brown quartzose marble beds are more abundant and thicker here than at Stop 2. Finally, note that the Standing Pond Volcanics that separate the rocks here from the Waits River to the west have not been observed anywhere along either contact of the western belt of Gile Mountain with the bounding Waits River (Doll and others, 1961). Regardless of the restored original distance between these two belts of exposure (shown as about 25 miles by Doll and others, 1961, cross section C-C′), it seems unusual that none of the Standing Pond volcanic tuff is preserved along or near the contacts of the western Gile Mountain belt. These relations are presumably trying to tell us something about the history of these rocks, but, to date, they have not spoken clearly enough. In any event, I suggest that, if the rocks here are stratigraphically correlative with the western Gile Mountain, they are a more proximal facies.

Return to the cars and continue east on Route 14.

37.7 Village of Sharon. Turn left (northeast) on Route 132.

37.9 Pass under Route I-89.

38.0 Park where you can near, but not obstructing, the Half Acre Motel.

STOP 7 (Sharon 7.5- minute quadrangle)

Walk up (west) the ramp toward Route I-89 North about 450 feet to the outcrops on the right. KEEP OFF THE RAMP ROADWAY

The rocks here are in the same belt, or tongue, west of the Strafford dome of Gile Mountain Formation as those seen at Stop 6. Here, beds of brown micaceous quartzite are as much as 3 feet thick and the intervening schists are very quartzofeldspathic and graphite free. Quartzose marble beds, although present here, are rarely more than a few inches thick. I interpret the protoliths of these rocks to have been coarser grained and more quartzofeldspathic than the protoliths of the rocks at Stop 2. They are mapped in figure 2 as the quartzite facies.

Return to the cars and continue northeast on Route 132.

40.8 Note gravel road to left to "High Lake", formerly known as Standing Pond. Would you believe the High Lake Volcanics? Continue northeast on Route 132.

42.2 Cuts on both sides of the road at the top of the rise are in the Waits River Formation in the core of the Strafford dome.

44.2 T intersection. Turn right (east) on Route 132 and proceed through village of South Strafford.

44.6 Route 132 turns left at the far end of the village--follow it.

46.5 The old Elizabeth Copper Mine is about 1/2 mile upslope to your right (south). Despite the mine having been closed for about 30 years, note the iron stain in the West Branch of the Ompompanoosuc River which you have been following.

48.9 Park close up on the right shoulder.

STOP 8 (South Strafford 7.5-minute quadrangle)

Outcrops are in the West Branch of the Ompomanoosuc River to your right. This locality is called Rices Mills on the South Strafford 7.5-minute and the old Strafford 15 minute quads.

The rocks here are brown to gray-brown, medium-grained micaceous quartzite and quartz-mica schist, with very minor quartzose marble. They have been mapped as Gile Mountain Formation, and I include them in the same "quartzite" facies as Stops 6 and 7. Beds are relatively faint and are a few inches to a few feet in thickness. Graphitic pelites are rare to absent. Again, I suggest that these rocks are a coarser grained, more rapidly deposited, more proximal facies than the rocks of the rhythmically graded western Gile Mountain facies seen at Stop 2.

Return to the cars and continue southeast on Route 132.

52.3 Make two left turns within about 50 feet. Follow signs to Union Village and Union Village Dam.

52.8 Bear slightly left. Do not turn right through covered bridge.

52.9 Enter grounds of Union Village Dam (U.S. Army Corps of Engineers).
Follow paved road up to top of dam and park around the flag pole.

STOP 9. (South Strafford 7.5-minute quadrangle).
This impressive structure is the U.S. Army Corps of Engineers Union Village flood control dam on the Ompompanoosuc River.

The rocks to be seen here have been assigned by Doll (1944) and by Doll and others (1961) to the Gile Mountain Formation and to the Meetinghouse Slate Member thereof. They are at the extreme eastern edge of the Connecticut Valley trough; the Monroe "line" or fault (Eric and others, 1941; Hatch, 1985, in press) that bounds the trough on the east passes within a few feet of the covered bridge that you just passed in the village. In this study, these rocks are mapped within the quartzite/metapelite facies and the metapelite facies (fig. 2).

From the flagpole, walk about 400 feet northwest to a set of pavement outcrops of interbedded dark-gray slaty phyllite and light-gray micaceous quartzite. The beds of micaceous quartzite are mostly 2 to 4 inches thick, and some are graded. The rocks and their bedding style here are somewhat similar to the rocks at Stop 2, but are clearly very different from the rocks at Stops 6, 7, and 8. Yet the rocks at Stops 2, 6, 7, 8, and 9 have been mapped previously as undifferentiated Gile Mountain Formation (excepting the separation of the Meetinghouse). I interpret the rocks here to have been deposited originally as fine silt and mud, in contrast to the rocks at Stops 6, 7, and 8 that I interpret to have formed as sand and muddy sand. Differences between the rocks here and those at Stop 2 are primarily that the rocks at Stop 2 are more regularly bedded (more consistent bedding thickness) and more consistently graded.

Structures readily seen in these outcrops include isoclinal folds, minor faults, and cleavages The dominant schistosity in the phyllites is parallel to the axial planes of the isoclines that are believed to be the earliest folds. The axes of these folds are subhorizontal. Many beds near fold hinges have been offset a few inches or more along planes that parallel the axial planar schistosity. Similar faulting has been observed elsewhere near the eastern edge of the trough. I suggest that the faulting and isoclinal folding were roughly synchronous and that both formed in a compressional regime during early stages of the Acadian orogeny. I further suggest that the minor faults seen here may be indicative of larger scale Acadian thrusting along the Monroe fault zone. Note the quartz veins that have been folded isoclinally with the beds, indicating that at least some of the quartz veins in these rocks formed early in the deformational history.

From these exposures, walk south about 500 feet to a vertical cut immediately north (upstream) of the concrete spillway dam. PLEASE do not cross over the spillway dam despite the tempting outcrops on the other side. Pertinent features can be seen on the north side of the dam. The rocks here are the same as those just seen, with the addition of some late structures. Conspicuous are kink folds and kink bands that deform both bedding and the dominant schistosity and appear to be the youngest structures in the rocks. The kink bands strike northeast, parallel to bedding and schistosity, but dip only about $40^{\circ}$ west in contrast to the essentially vertical bedding and schistosity. Also present here is a 3-inch-wide zone of brittle crushing that parallels the early schistosity. Similar kink bands are present along the trend of the Monroe fault to the north and south, as well as along the Ammonoosuc fault to the northeast. Similar crushed zones are displayed very well to the north at the point where the Monroe fault crosses the new cuts for Route I-93, a few miles west of Concord, Vermont. All of these structures are interpreted to have formed as a result of Mesozoic extensional normal faulting, extending north from the Mesozoic basins along the Connecticut River valley in Connecticut and Massachusetts.

Walk up the slope, past the cars, and continue along the road across the top of the dam to outcrops at the east end of the dam. In this vertical cut, you can see more isoclinal fold hinges and more truncations along vertical planes parallel to the early schistosity. The hinges of the isoclines appear to plunge very gently north to horizontal. Note the presence here of some quartz veins that are significantly thicker (6 to 12 inches) than those at the west end of the dam. They cut both beds and schistosity and, thus, are later than other thinner veins here that parallel schistosity and may be of the earlier generation. Perhaps these later thicker quartz veins are Mesozoic.

A few hundred feet southeast down the now blocked-off road is an exposure in which two sets of kink bands can be seen dipping moderately northwest and southeast. This conjugate set suggests vertical compression, compatible with the vertical crushed zone at the west end of the dam and with Mesozoic extension. Continue about 500 feet southeast down the blocked-off road to a small exposure on the left of dark-gray, graphitic slate typical of the Meetinghouse Slate.

Continue south down the blocked-off road. Turn right on the paved road and follow it about 1,000 feet south. About 90 feet before the covered bridge (yes, the same one you saw driving in) is an outcrop on the right of greenstone with excellent slickenlines plunging directly down the subvertical slickenside surface that parallels the schistosity. This rock was mapped by Doll (1944) and by me as being immediately southeast of the Monroe fault. I interpret the slickensiding to be Mesozoic and related to the crush zone and the kink folds and kink bands that you have just seen. Continue through the covered bridge to the T intersection. Meetinghouse Slate is exposed at a number of small outcrops here. Turn right at the T and walk back up to the cars at the top of the dam.

This is the end of the trip.

For the fastest route back to Northfield, retrace the roadlog back to Stop 7 (Mile 38.0 on the roadlog) and turn right up the ramp onto Route I-89 North. Follow Route I-89 North to Exit 5 and take Route 64 west to Route 12 to Northfield Center and Norwich University.

For the fastest route south, go back down to Union Village and follow Route 132 South to Route 5 south to Norwich where you can pick up Route I-91 South which in turn leads to Route I-89 South.