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Tectonic Setting of the Northern Part of the Green Mountain Massif, Vermont

Karabinos, Paul

TECTONIC SETTING OF THE NORTHERN PART OF THE GREEN MOUNTAIN MASSIF, VERMONT[1]

Paul Karabinos
Department of Geology
Williams College
Williamstown, MA 01267
and
U.S. Geological Survey
Reston, Va 22092

INTRODUCTION

The Green Mountain massif in southern Vermont is cored by Middle Proterozoic basement rocks of the Mount Holly Complex (Doll et al., 1961; Fig. 1). The massif is bordered on the west by a sequence of Late Proterozoic to Middle Ordovician conglomerates, quartzites and marbles containing minor amounts of phyllite. This western sequence of cover rocks was deposited in shallow water on the continental shelf of ancient North America, and is blanketed by Middle Ordovician synorogenic flysch, which heralded the arrival of the Taconic thrust sheets (Cady, 1945; Rodgers, 1968). The basement rocks of the massif are bordered to the east by a very different cover sequence of Late Proterozoic to Lower Cambrian conglomerates, graywackes, and pelitic and mafic schists containing minor amounts of quartzite and marble. Farther east of the eastern cover sequence are mafic and pelitic schists and bimodal metavolcanic rocks of unknown but presumed Cambrian to Middle Ordovician age (Doll et al., 1961; Zen et al., 1983). These rocks may be remnants of an accretionary wedge and island arc complex (Rowley and Kidd, 1981; Stanley and Ratcliffe, 1985).

The basement rocks of the Mount Holly Complex were deformed during the Middle Proterozoic Grenville orogeny. These rocks, together with the cover sequences, were deformed and metamorphosed during the Ordovician Taconian and Devonian Acadian orogenies (Zen, 1967; Rosenfeld, 1968; Hepburn, 1975; Laird and Albee, 1981; Sutter et al., 1985). Within the map area of Figure 2, the Paleozoic metamorphisms reached no higher than biotite grade, except for some rocks in the northwest part of the area which reached garnet grade. The Grenville metamorphism occurred at higher temperatures, however, with the result that pegmatites are common in basement rocks of the Mount Holly Complex in the

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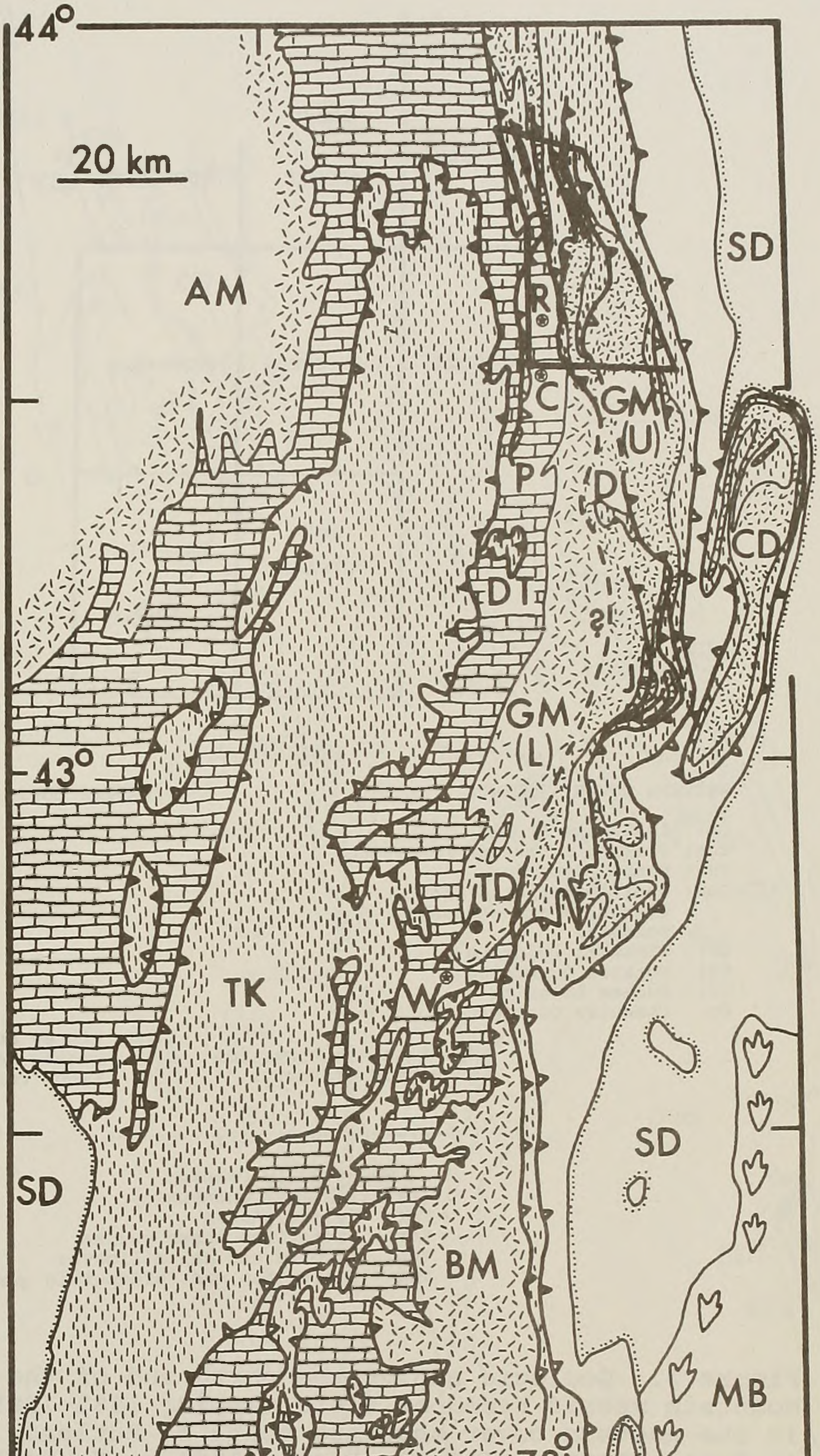
Figure 1. Generalized tectonic map of western New England and eastern New York. Brick pattern- Late Proterozoic to Middle Ordovician western shelf sequence and Middle Ordovician synorogenic flysch; vertical dashed pattern- Late Proterozoic to Middle Ordovician slope-rise sequence; coarse hatchured pattern- Middle Proterozoic basement unconformably overlain by western cover sequence rocks; fine hatchured pattern- Middle Proterozoic basement unconformably overlain by eastern cover sequence rocks; unpatterned unit- presumed Cambrian to Ordovician remnants of an accretionary wedge and island arc complex; SD- Silurian and Devonian formations; MB- Mesozoic basin. Major tectonic features: AM- Adirondack massif; BM- Berkshire massif; CD- Chester dome; GM(U)- structurally higher tectonic unit in the Green Mountain massif; GM(L)- structurally lower tectonic unit in the Green Mountain massif; TK- Taconic klippen. Minor tectonic features and locations: C- Clarendon, VT; D- Devils Den exposure of cover rocks; DT- Dorset thrust sheet; J- Jamaica, VT; P- Pine Hill thrust; R- Rutland, VT; TD- The Dome; W- Williamstown, MA. Polygon shows area of Fig. 2. Heavy lines- thrust faults, teeth point to upper plate. Based on Doll et al. (1961), Zen et al. (1983), Thompson et al. (1982), Karabinos and Thompson (1984), Stanley and Ratcliffe (1985), and Thompson and McLelland (in press).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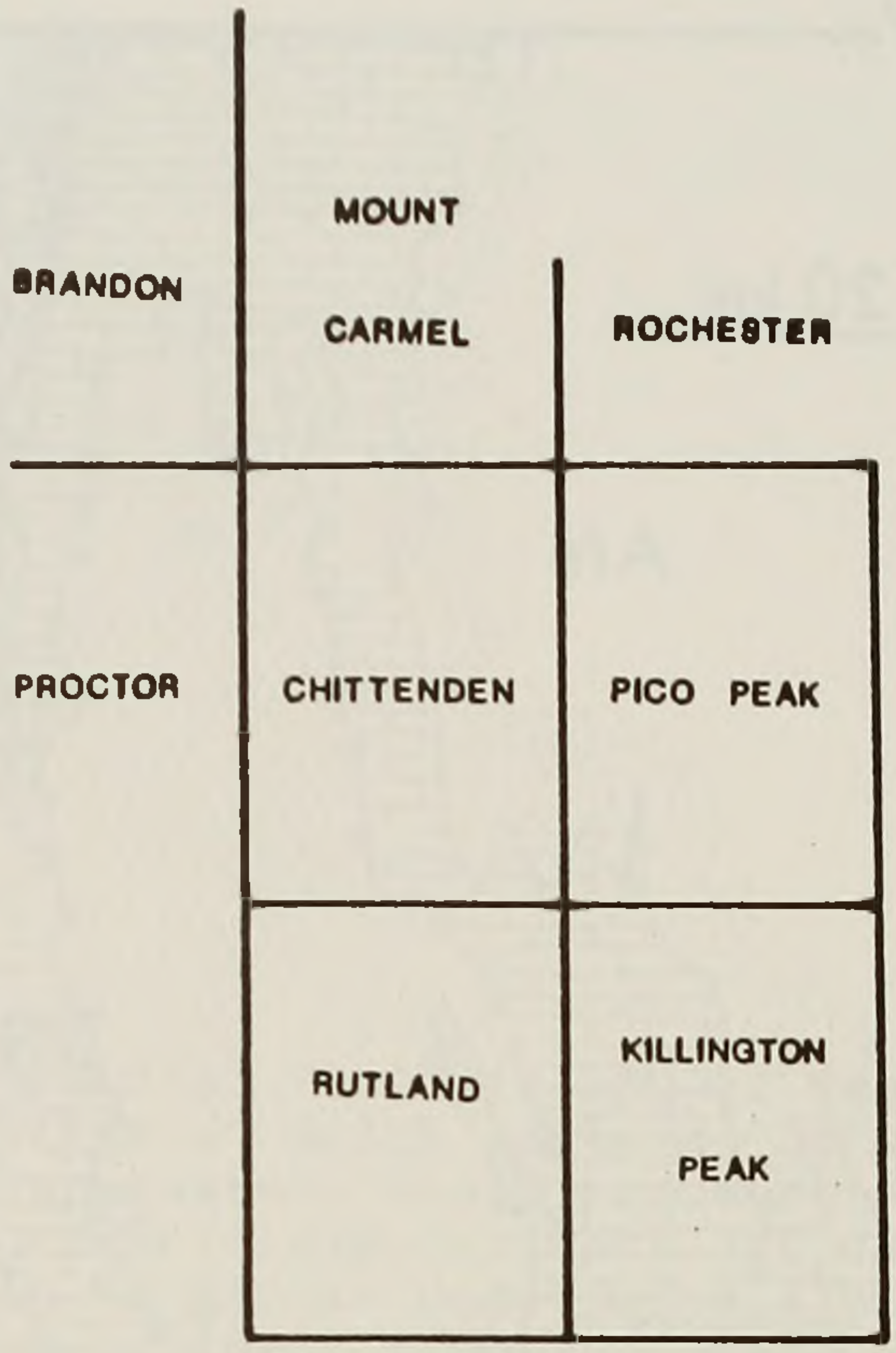


EXPLANATION

WESTERN COVER SEQUENCE

Os: Shelburne Marble
€cs: Clarendon Springs Formation
€da: Danby Formation
€mw: Undifferentiated Monkton Quartzite and Winooski Dolomite
€w: Winooski Dolomite
€m: Monkton Quartzite
€d: Dunham Dolomite
€c: Cheshire Quartzite

€Zp: Pinnacle Formation (uncertain affinity)

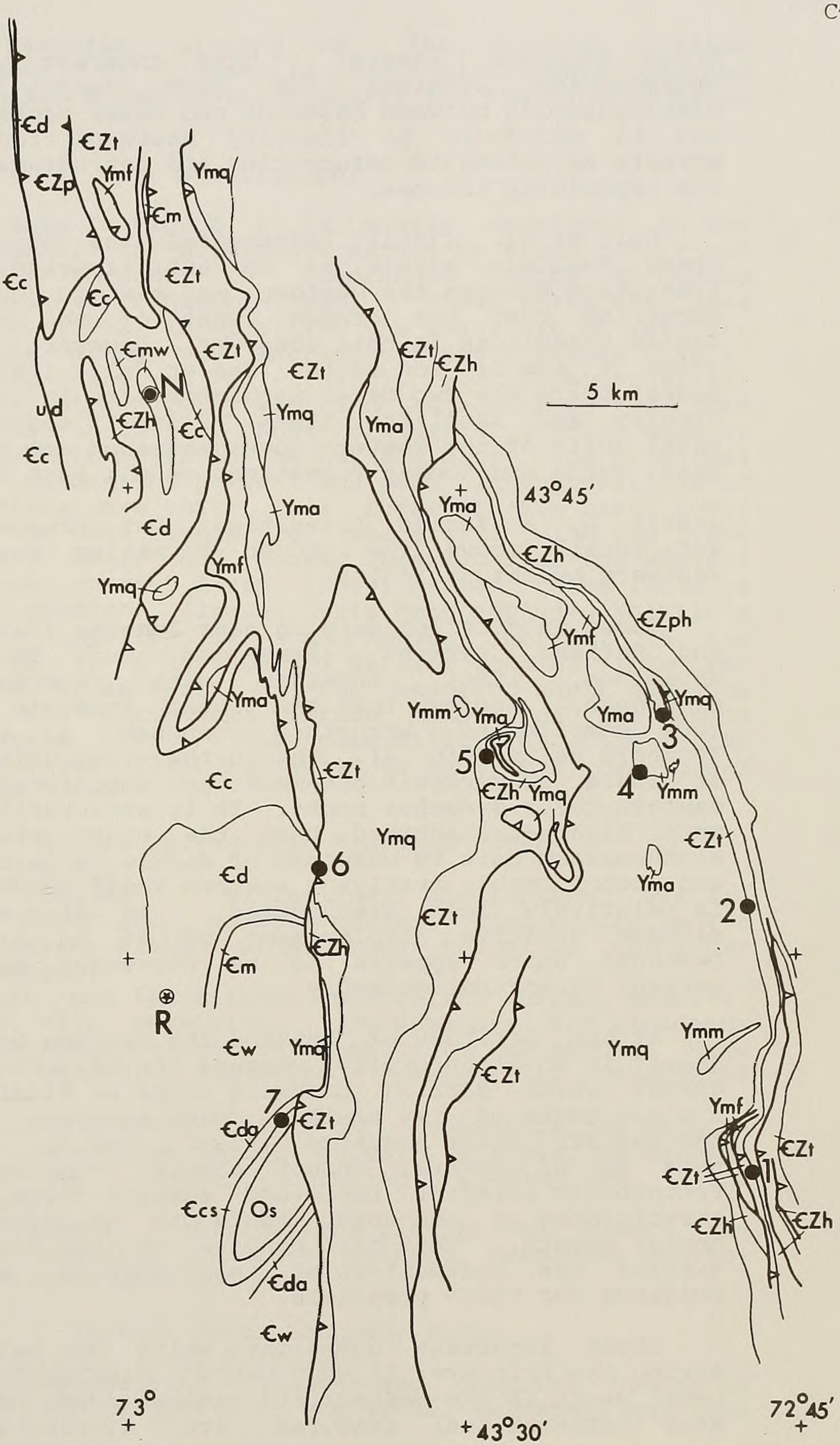
EASTERN COVER SEQUENCE

€Zph: Pinney Hollow Formation
€Zh: Hoosac Formation
€Zt: Tyson Formation

-------- unconformity --------

Mount Holly Complex
(Relative ages uncertain)
Ymf: Felsic gneiss
Yma: Microcline augen gneiss
Ymm: Marbles and calcsilicates
Ymq: Quartzites and feldspathic quartzites

Figure 2. Geologic map of the north end of the Green Mountain massif based of field mapping 1981-1985. Structure in the western cover sequence south of Rutland, VT (R) based on Brace (1953) and Doll et al. (1961). N- Nickwacket Mountain. Heavy lines- thrust faults, teeth point to upper plate.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Green Mountain massif. This contrast in grade of metamorphism provides the most useful method for distinguishing between basement and cover rocks, although it can be difficult to identify basement rocks where the effects of Paleozoic deformation and retrograde metamorphism are especially intense.

Doll et al. (1961) interpreted the structure of the Green Mountain massif as an anticlinorium with a facies transition between the western and eastern cover sequences occurring over the eroded crest of the massif. Such a facies transition is not observed, however, at the north (Figs. 1 and 2) and south (Zen et al., 1983) ends of the massif where the two cover sequences are in fault contact. Stanley and Ratcliffe (1985, Plate 1) suggested that the basal units of the western cover sequence are related to the basal Tyson and Hoosac Formations on the east side of the massif by a facies transition, but proposed that units structurally above the Hoosac Formation were transported westward by thrust faults.

Based on detailed mapping near Jamaica (Karabinos, 1984) and Rutland, Vermont (Karabinos and Thompson, 1984; Karabinos, 1986), together with reconnaissance work elsewhere, I suggest that the Green Mountain massif is a more complicated structure composed of two different tectonic units (Fig. 1). The northeastern unit is composed of Middle Proterozoic basement and unconformably overlying eastern cover sequence rocks. It is structurally higher and more highly-transported than the southwestern unit. The southwestern unit is composed of Middle Proterozoic basement and unconformably overlying western shelf sequence rocks and is relatively less transported. As discussed later, a minimum relative displacement of 16 km between the two tectonic units appears to be necessary to explain the current structural geometry.

At the latitude of Rutland the eastern boundary of the massif is an unconformity, whereas the western boundary is a thrust which carried basement rocks of Middle Proterozoic age and rocks of the eastern cover sequence westward over the western shelf sequence (Figs. 1 and 2). The massif is made up of several thrust sheets composed of Middle Proterozoic basement rocks and eastern cover rocks and the stratigraphy of the cover rocks can be correlated between thrust sheets. The main purpose of this field trip is to examine the basement-cover relationships which provide evidence for these proposals.

Other important questions which may help fuel debate during the trip are: 1) How can we distinguish between the basal parts of the western and eastern cover sequences?, 2) what deformational features are attributable to the

Ordovician Taconian orogeny vs. the Devonian Acadian orogeny?, and 3) what is the relationship between thrusting in the Green Mountain massif and the Taconic Range to the west?

Stratigraphy

The map area in Figure 2 is mostly contained in the Rutland, Vermont, 15' quadrangle mapped by Brace (1953) and the Rochester, Vermont, 15' quadrangle mapped by Osberg (1952, unpublished manuscript map). These works were used by Doll et al. (1961) in compiling the state map of Vermont. These authors along with MacFadyen (1956), Skehan (1961), Hewitt (1961), Chang et al. (1965), and Thompsón (1967) describe the stratigraphy in and adjacent to the Green Mountain massif in detail. What follows is a brief summary of the lithologic units in the Rutland area. The principal differences between the present and past interpretations of the stratigraphy are that: 1) I correlate the basal cover rocks along the west boundary of the massif with the Tyson (Doll et al, 1961) and Hoosac Formations of the eastern cover sequence, whereas Brace (1953) mapped these rocks as the Mendon Formation. (Indeed, this belt includes Whittle's (1894) type locality of the Mendon Series, in his terminology); 2) I have mapped marbles west of Nickwacket Mountain (Fig. 2) as part of the western shelf sequence instead of the Forestdale Marble Member of the Mendon Formation (Brace, 1953). The possibility of this latter interpretation was first suggested to me by P.H. Osberg and J.B. Thompson, Jr..

Middle Proterozoic Basement Rocks

Mount Holly Complex

Yma, Augen Gneiss: Microcline, plagioclase, quartz, biotite, muscovite, epidote gneiss. Also occurs as 1-3 m thick layers within other rock types in the Mount Holly Complex.

Ymq, Quartzite and feldspathic quartzite: Clean, massive, vitreous, blue quartzite. Feldspathic and micaceous quartzite commonly containing chlorite and garnet. Rare beds of quartz, muscovite, paragonite, chloritoid schist.

Ymm, Marble and calc-silicate rock: Coarse-grained calcite marble. Tremolite, talc, calcite, epidote, phlogopite schist; may contain chlorite, plagioclase, and microcline.

Ymf, Felsic Geisses: Heterogeneous plagioclase, quartz, ±K-feldspar, biotite, chlorite, epidote, muscovite gneiss; may contain altered garnet.

Eastern Cover Sequence Rocks

Tyson (Doll et al., 1961) Formation

ЄZtc, Basal Conglomerate: Sand-sized detrital grains to boulders of blue quartz or quartzite, feldspar, and less commonly lithic fragments of gneiss in a matrix of quartz, albite, muscovite, biotite, chlorite schist.

€Zts, Schist: Quartz, albite, muscovite, chlorite, biotite schist; commonly contains weathered pits and nodules of carbonate minerals. Light gray carbonate-rich quartz, muscovite schist.

€Ztq, Quartzite: Light gray, fine-grained quartzite containing minor amounts of muscovite and feldspar.

€Ztd, Dolomite: Fine-grained, buff-weathering, massive dolomite; many beds contain detrital quartz grains. Magnetite-rich near upper contact with Hoosac Formation.

Hoosac Formation

€Zh, Albite Schist: Albite porphyroblast, quartz, biotite, muscovite, chlorite schist near base. Dark gray graphitic quartz, albite, muscovite, biotite, chlorite phyllite; commonly contains beds of dark quartzite, rarely contains thin beds of dolomite.

Pinney Hollow Formation

€Zph, Green phyllite: Quartz, albite, muscovite, chlorite phyllite or fine-grained schist. Quartz, muscovite, paragonite, chloritoid, chlorite phyllite. Less commonly albite-porphyroblast, quartz, muscovite, biotite, chlorite schist. Includes epidote, chlorite, quartz, plagioclase, muscovite greenstone.

Rocks of Uncertain Affinity

Pinnacle Formation

€Zp: Medium to dark gray quartz, feldspar, biotite, muscovite, chlorite metagraywacke. Detrital grains of quartz, feldspar, and mica typical. Well bedded. Contains beds of quartz, albite, muscovite, biotite, chlorite schist.

Western Cover Sequence Rocks

Cheshire Quartzite

€c: White, vitreous, massive quartzite. Interbeds of dark gray quartz, muscovite, biotite, chlorite phyllite and feldspathic, micaceous quartzite common near base.

Dunham Dolomite (Doll et al., 1961)

€d: Buff-weathering dolomite containing siliceous partings and detrital quartz grains.

Monkton Quartzite and Winooski Dolomite

€mw: Interbedded impure quartzite and buff, orange, yellow, or dark gray dolomite. Green and dark gray beds of phyllite also present. Winooski Dolomite contains somewhat less quartzite than the Monkton Quartzite. Difficult to separate these units in the Rutland area.

Danby Formation

€da: Vitreous quartzite interbedded with gray calcitic dolomite. Dolomitic quartzite and quartzose dolomite. Cross-bedding common.

Clarendon Springs Formation

€cs: Gray calcitic dolomite.

Shelburne Marble

Os: White calcite marble. Intermediate gray dolomite unit.

Ira Formation

Oi: Dark gray quartz, muscovite, biotite, chlorite phyllite; contains beds of blue-gray calcite marble.

Basement-cover relationships

The contact between the basement rocks of the Middle Proterozoic Mount Holly Complex and the Late Proterozoic to Lower Cambrian Tyson Formation is a well documented unconformity along the east margin of the Green Mountain massif. Dale (1916) interpreted this contact as an unconformity and so has every other worker who has mapped it in detail, including Thompson (1950), Rosenfeld (1954), Brace (1953), Skehan (1961), Chang et al. (1965), Karabinos (1984), and Karabinos and Thompson (1984). We will see this contact at Stop 2.

The extent of stratigraphic continuity upward from the unconformity, within the cover sequence, is an important issue to resolve. Doll et al. (1961) showed the cover sequence east of the Green Mountain massif as a homoclinal sequence in which rocks become progressively younger to the east, with a major unconformity between Ordovician and Silurian formations. Zen et al. (1983), however, mapped the equivalent rocks along strike to the south in Massachusetts with numerous thrust faults dissecting the sequence. Ratcliffe and Hatch (1979) and Stanley and Ratcliffe (1985) proposed that the cover sequence east of the Green Mountain massif and around the Chester dome also contains faults at about the same position as the Hoosac Summit and Whitcomb summit thrusts of northern Massachusetts. Recent mapping (e.g. Karabinos, 1984; Thompson et al., 1982; Thompson and McLelland, in press) shows that thrust faulting was important, but more mapping is needed to correlate faults in southeastern Vermont with thrusts mapped elsewhere.

Based on detailed mapping near Jamaica and Rutland, Vermont (Karabinos, 1984, 1986; Karabinos and Thompson, 1984) and the work of others (Osberg, 1952; Brace, 1953; Skehan, 1961; Chang et al., 1965; and Thompson, 1972) I interpret the Tyson, Hoosac, and Pinney Hollow Formations as being stratigraphically continuous. In the Jamaica, Vermont area and at the north end of the Green Mountain massif the contact between the Hoosac and Pinney Hollow Formations is gradational and is not marked by evidence for strain gradients indicative of thrusting (Karabinos, 1984; Karabinos and Thompson, 1984). There are also many rock types common to the Tyson, Hoosac, and Pinney Hollow Formations suggesting that they were not deposited in dramatically different environments. Furthermore, the contacts do not show the persistent stratigraphic truncations used by Knapp and Stanley (1978), Stanley (1978, 1982), and Ratcliffe (1979) as evidence for thrusting in the

Rowe Schist in Massachusetts. Primary sedimentary structures are rarely preserved in the Tyson, Hoosac, and Pinney Hollow Formations, but their lithologies suggest that they were deposited in a deeper water environment than the quartzites and marbles of the shelf sequence. Zen (1967) and Thompson (1972) correlated these formations with rocks in the Taconic sequence to the west, some of which were deposited in a slope-rise environment (Friedman, 1979; Rowley et al., 1979). If this interpretation is correct, discontinuous quartzites and marbles in the Tyson and Hoosac Formations may have originated as sedimentary lenses (Skehan, 1961; Chang et al., 1965) and may have been derived from shelf rocks to the west. Keith and Friedman (1977) proposed that similar quartzite and marble lenses in Cambrian rocks of the Taconic sequence formed by fluidized sediment flows and debris flows, which carried shelf derived material into deeper water. I have correlated cover rocks occurring in thrust sheets in the northern part of the massif with the Tyson and Hoosac Formations (Fig. 2) based on the similarity and sequence of lithologies.

On the west side of the massif south of Clarendon, Vermont (Fig. 1) the contact between the Mount Holly Complex and the Late Proterozoic to Lower Cambrian Dalton Formation is an unconformity (MacFadyen, 1956; Thompson, 1959; Skehan, 1961; Hewitt, 1961; Doll et al., 1961; Zen et al., 1983). The Dalton Formation is conglomeratic near the unconformity and phyllitic near its upper contact with the Cheshire Quartzite. It is not uncommon, however, for the conglomerate to grade directly into massive quartzite beds of the Cheshire Quartzite and for the intervening phyllite to be absent. The Dalton Formation is particularly thin and lacking in phyllite in the Wallingford, Vermont, 15' quadrangle (J.B. Thompson, Jr. and E. Downie, personal communications, 1985) just south of the map area shown in Figure 2.

Detailed mapping in the Killington Peak, Rutland, Pico Peak, Chittenden, Mount Carmel, and Brandon, Vermont, 7 1/2' quadrangles during the summers of 1981-1985 indicates that the western boundary of the Green Mountain massif north of Clarendon, Vermont is a major thrust fault (Figs. 1 and 2; Karabinos and Thompson, 1984; Karabinos, 1986). Rocks of the western shelf sequence, varying in age from the Early Cambrian Cheshire Quartzite to the Early Ordovician Shelburne Marble, structurally underlie basement rocks of the Mount Holly Complex or cover rocks which I interpret as basal units of the eastern cover sequence (Fig. 2). The cover rocks in the hanging-wall of the fault typically contain the sequence, upward from the basement contact: pebble to boulder conglomerate in a graywacke matrix; graywacke, commonly containing weathered carbonate grains and nodules and beds of quartzite and phyllite 1 m to 100 m thick; light gray quartzite; dolomitic marble; and albite-bearing phyllite or schist locally interlayered with chloritoid-paragonite phyllite. These lithologies and their sequence are very similar to the common units in the Tyson and lower part of the Hoosac Formations on the east side of the massif at this latitude.

As shown in Figure 2, the Green Mountain massif at the latitude of Rutland is made up of several thrust sheets composed of Middle Proterozoic basement and Late Proterozoic to Lower Cambrian cover rocks belonging to the eastern cover sequence. Despite folding of the thrust sheets by later deformation, it is still possible to recognize stratigraphic truncations along fault boundaries.

The basement-cover relationships suggest that the Green Mountain massif is made up of two different tectonic units. Middle Proterozoic basement rocks of a structurally higher, more highly-transported unit are unconformably overlain by the eastern cover sequence. The upper part of this cover sequence (Hoosac, and Pinney Hollow Formations) was probably deposited in a slope-rise environment, as discussed above. The lower part of the sequence probably represents rift clastic deposits. Basement rocks of a structurally lower, relatively less transported unit in the southwestern portion of the massif are unconformably overlain by the western cover sequence dominated by quartzites and marbles deposited in a shelf sequence (Cady, 1945; Rodgers, 1968). The boundary between these two tectonic units is poorly constrained in the central and southern interior of the massif where detailed mapping is incomplete and exposure rather spotty, and it need not be an east-dipping thrust along its entire length. E. Downie and J.B. Thompson, Jr. (personal communications, 1986) suggested that the boundary could instead be a normal fault west of the Devils Den exposure of cover rock (Fig. 1). Another possibility is that some portions of the boundary are west-dipping back thrusts with eastward displacement of western cover sequence rocks and the underlying basement.

Conditions and age of thrust faulting

Where the location of thrust faults is well bracketed and samples have been collected, thin section analysis shows that in fault zones quartz deformed in a ductile fashion with extensive recrystallization, whereas feldspar deformed brittlely (Karabinos, 1986). Paleozoic metamorphism did not exceed biotite grade conditions in the area of Figure 2, except for a small region in the northwest part of the map area. Thrusting, therefore, probably occurred at biotite grade conditions.

Without independent information on the facies relationships between the western and eastern cover sequences, it is difficult to estimate the displacement on thrusts in the northern part of the Green Mountain massif required to produce the observed juxtaposition of the two cover sequences. The basal lithologies of the two cover sequences are similar (Dalton Formation on the west side and Tyson Formation on the east side) but the overlying Cheshire Quartzite and Dunham Dolomite of the western sequence are, in general, quite distinct from the correlative Hoosac and Pinney Hollow Formations of the eastern cover sequence. Thompson (1972), however, correlated the Plymouth member of the Hoosac Formation with the upper part of the Cheshire Quartzite and the lower part of the Dunham Dolomite because of striking similarities in lithologies and textures. It appears, therefore, that similar depositional processes may have operated in both sequences during part of their development. It is also worth noting that if Stanley and Ratcliffe (1985) are correct in their proposal that the contact between the Hoosac and Pinney Hollow Formations east of the Green Mountain massif and around the Chester dome is a thrust, then the contrast between the cover sequences on the west and east side of the massif need not be too great. As described above, however, I interpret the Tyson, Hoosac, and Pinney Hollow Formations as being stratigraphically continuous. If this interpretaion is correct, the significant lithological differences between the pelitic and mafic schists in the Pinney Hollow Formation and correlative units in the western shelf sequence (see Thompson, 1972) indicate that the eastern and western cover sequences were deposited in quite different environments when the Pinney Hollow Formation formed.

An important problem is the possibility of north to south facies variations in the cover rock sequences in addition to east to west variations. Dowling et al. (1987) described north to south facies variations in the Late Proterozoic Oak Hill Group of southern Quebec and correlative units in the Camels Hump Group of northern Vermont. Such north to south variations may be important north of the Green Mountain massif (cf. Tauvers, 1982), however, they do not appear to be dramatic at the latitude of the Green Mountain massif. Along the western boundary of the massif, south of Clarendon to the thrust fault in Pownal, Vermont exposed on the mountain called The Dome (Fig. 1), near the Vermont-Massachusetts border, the Dalton Formation and the Cheshire Quartzite maintain a fairly uniform thickness (Doll et al., 1961) and the most important variation is the presence or absence of the phyllite unit in the upper part of the Dalton Formation discussed above. South of thrust on The Dome, the Dalton Formation is significantly thicker than it is to the north (Zen et al., 1983), but the thrust has truncated the details of the transition in the Dalton Formation. Along the eastern boundary of the massif from its northern end south to Jamaica, Vermont, the Tyson, Hoosac, and Pinney Hollow Formations maintain an approximately uniform thickness (Doll et al., 1961) and the most important variation is the presence or absence of the Plymouth Member of the Hoosac Formation. From Jamaica south to approximately the Vermont-Massachusetts border, two distinctive sequences of the basal cover rocks are separated by thrusts (shown by Doll et al. (1961) without intervening faults as the Cavendish Formation vs. the Tyson and Hoosac Formations). Skehan (1972) suggested that these two sequences could be coeval, represent east to west facies variations of each other, and be separated by thrusts. Karabinos (1984) presented structural evidence in support of these suggestions based on mapping near Jamaica, Vermont and recent mapping by N.M. Ratcliffe (shown in Zen et al. (1983) and unpublished) in southern Vermont also indicates that two distinctive cover sequences are separated by thrusts. These east to west variations in the basal cover rock sequences are similar to those described by Ratcliffe (1979) and Ratcliffe and Hatch (1979) in Massachusetts and southern-most Vermont.

The age of faulting in the northern part of the Green Mountain massif is poorly constrained; it could be part of the Taconian or Acadian orogenies, or there may have been more than one episode of thrust faulting. Uncertainty in the correct age assignment of faults in the eastern Taconic klippen, the Berkshire and Green Mountain massifs, and in complexly deformed cover rocks east of the massifs imposes a major limitation on our tectonic and palinspastic reconstructions of western New England. Stanley and Ratcliffe (1985) proposed that during the Taconian orogeny, thrusting became generally younger to the east away from the transport direction of the thrust sheets. Thus, late Taconian (and possibly Acadian) thrusts may truncate early Taconian thrusts. Later thrusting would not only complicate the structural geometry of the Taconian thrust belt but also the palinspastic reconstruction of the relative depositional sites of cover rocks from different thrust sheets.

Until much-needed radiometric dating of fault zone material becomes available, I think it is reasonable to correlate thrusting in the massif with Taconian faulting elsewhere in western New England (Taconic Range: Zen, 1967; Ratcliffe, 1979; Bosworth and Rowley, 1984; Berkshire massif: Ratcliffe and Harwood, 1975; Norton, 1975; Ratcliffe and Hatch, 1979; northern Vermont: Stanley and Roy, 1982; Stanley et al., 1982), although Acadian faulting is also recognized in western New England (Ratcliffe, 1979).

In support of this tentative correlation, the stratigraphic separation on the east side of the Taconic Range near Rutland, Vermont is very similar to that along the west boundary of the massif as shown in Figure 2. On the east side of the Taconic Range, basal Cambrian or Late Proterozoic units of the Taconic sequence, Biddie Knob, Bull, and West Castleton Formations of Zen (1964) and Netop and St. Catherine Formations of Thompson (1967), structurally overlie Ordovician formations of the western shelf sequence or the Middle Ordovician synorogenic flysch blanketing the shelf sequence. On the northwest side of the Green Mountain massif, Middle Proterozoic basement and Late Proterozoic to Cambrian eastern cover sequence rocks of the Tyson and Hoosac Formations overlie Cambrian to Ordovician rocks of the western shelf sequence (Fig. 2). Virtually all the rock types found in the Hoosac and Pinney Hollow Formations, with the exception of mafic schists, are present in the basal units of the Taconic sequence near Rutland. In particular, Thompson (1967, p. 87) noted the strong resemblance of the pairs Netop-St. Catherine in the Dorset thrust sheet and the Hoosac-Pinney Hollow Formations east of the Green Mountain massif described by Chang et al. (1965). Therefore, it is possible that the sole faults on the east side of the Taconic Range, at least that of the Dorset thrust sheet, and the northwest margin of the Green Mountain massif were once continuous and that the fault cut up section to the west in the transport direction. If the sole faults of the Dorset thrust sheet and the northwest margin of the Green Mountain massif were once continuous, a minimum thrust displacement of approximately 16 km is necessary to account for the current structural geometry (Fig 1). Naturally, a much larger thrust displacement is possible.

Although the basement-cover relationships indicate that the massif is made up of two tectonic units, it is unclear at present how much relative displacement between these units occurred. If the western Taconic klippen (group 1 and 2 of Stanley and Ratcliffe, 1985) were deposited east of the Chester dome and were thrust over rocks of the Green Mountain massif as suggested by Stanley and Ratcliffe (1985) the relative displacement between the southwestern and northeastern tectonic units of the Green Mountain massif may be as little as 16 km as discussed above. If, however, the western Taconic klippen represent a transitional cover sequence between the western shelf sequence and cover rocks presently east of the Green Mountain massif as suggested by Zen (1967) the relative displacement between the two tectonic units in the massif must be greater than approximately 60 km to account for the present structural geometry (Fig.1).

Thrust faults are also present in the western cover sequence in the Vermont valley such as the Pine Hill thrust (Fig. 1; Wolff, 1891; Dale, 1894; Brace, 1953; Zen, 1964; Thompson, 1967). Thrusts involving Middle Proterozoic basement and the western cover sequence may form a duplex structure (Boyer and Elliott, 1982) which appears to extend beneath the Green Mountain massif and the Taconic Range. Ando et al. (1984) presented seismic evidence compatible with this interpretation (see also Stanley and Ratcliffe, 1985). A duplex beneath the Green Mountain massif would also help account for its anticlinorial structure.

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ITINERARY

Assembly point is parking lot on east side of Route 100 across from ski area in West Bridgewater, Vermont, 0.3 miles south of intersection of Routes 100 and 4.

Mileage

0.0 Drive south on Route 100.

This stretch of the valley followed by Route 100 is underlain by dolomite. The steep slope to the west is held up by resistant rocks of the Middle Proterozoic Mount Holly Complex and the Late Proterozoic to Lower Cambrian Tyson Formation. The steep slopes to the east are formed by the aluminous schists of the Late Proterozoic to Lower Cambrian Hoosac and Pinney Hollow Formations.

1.1 Quarry in dolomite of the Tyson Formation east of road. Outcrop of quartzite of the Tyson Formation next to road on east and in stream to west.

1.6 North end of Woodward Reservoir

2.8 STOP 1.Parking loop on west side of Route 100 just south of Woodward Resevoir.

On west side of outcrop, where the steep slope meets the parking area, is east-dipping, light gray, clean quartzite of the Tyson Formation. Heading east, the rock types are variable: quartz-rich muscovite, biotite, chlorite schist; thin layers of albite porphyroblast schist; quartz-pebble conglomerate in a quartz matrix, a schistose dolomite matrix, and dolomitic quartz matrix.

On the east side of Route 100 in an abandoned quarry is a good exposure of the dolomite member of the Tyson Formation. Many layers contain detrital quartz grains. The dolomite is typically massive and buff weathered, and sedimentary structures are

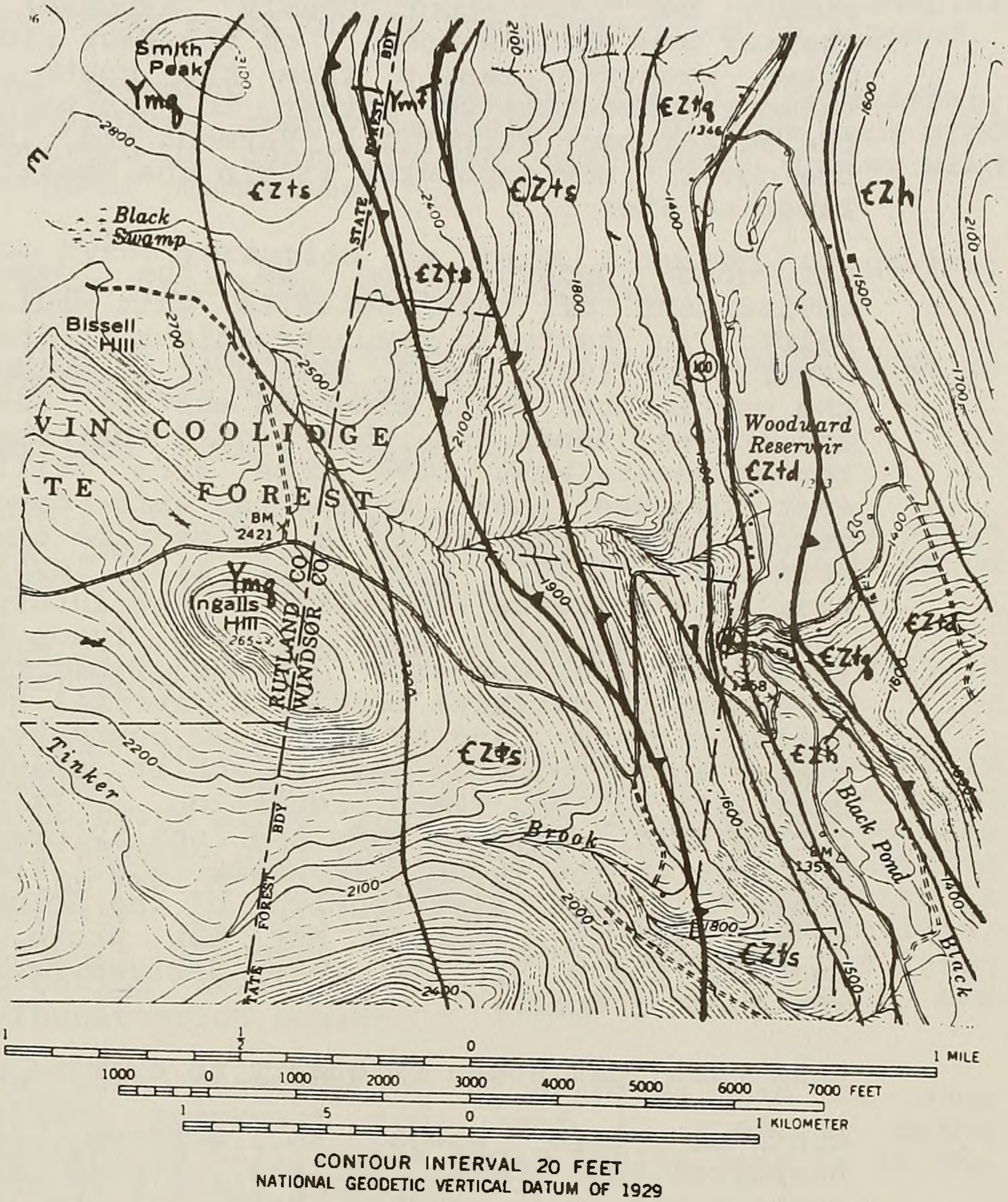

Figure 3. Photocopy of a portion of the Killington Peak 7 1/2' quadrangle showing the location of Stop 1. See Stratigraphy section in text for description of geologic units.

rarely preserved. The depositional environment of this unit is difficult to reconstruct. It is widely but not continuously exposed: in the Chester and Athens domes, on the east side of the Green Mountain massif from the south near the Vermont-Massachusetts border to the north end of the massif near Pittsfield, Vermont and in some of the cover rock exposures within the massif as seen later at Stop 5.

(A good understanding of the depositional environment of this dolomite unit would be most helpful in tectonic reconstructions. Stanley and Ratcliffe (1985) used this unit as evidence that the continental shelf extended east of the Chester and Athens domes and then argued that the Taconic thrust sheets must have come from still farther east because their sediments were deposited in deeper water, presumably a slope-rise environment (Friedman, 1979; Rowley et al., 1979). The available evidence also permits the interpretation that the dolomite unit of the Tyson Formation formed as slump deposits derived from the shelf. It commonly contains beds with detrital quartz and dolomite grains, and at its lower boundary the unit grades into dolomite-bearing schist, graywacke, or quartzite of the Tyson Formation. It is worth noting that dolomite beds are locally present near the base of the Taconic sequence (e.g., Zen, 1967), therefore, the distribution of the dolomite unit of the Tyson Formation may not prove that the Taconic thrust sheets were derived from east of the Chester dome.)

Walk east just south of quarry to examine dolomite.

Continue into woods to outcrop of albite porphyroblast schist of the Hoosac Formation. Contact not well exposed here, but the lower part of the Hoosac contain minor magnetite. This is very common where the contact between the dolomite unit and the Hoosac Formation can be closely bracketed (see also Thompson, 1972; and stop 5, this trip).

Return to cars and drive north on Route 100.

5.9 Intersection of Routes 4 and 100, West Bridgewater.

Continue north on Route 100 and west on Route 4.

9.2 STOP 2. Pull over on east side of road and cross highway to outcrop on west side.

The description of this outcrop is from Thompson (1972). It is duplicated here because the contact between basement rocks of the Mount Holly Complex and cover rocks of the Tyson Formation is exposed.

The basement lithology is quartz, K-feldspar, plagioclase, muscovite gneiss. Upslope are good outcrops of quartzite and quartz-rich gneiss with abundant pegmatites.

The Tyson Formation is here composed of quartz, albite, muscovite, chlorite schist.

A folded gneissic fabric in the basement rocks is truncated at the unconformity.

Continue north on Route 100.

10.1 Turn right onto River Rd. Again, the valley which the road follows is underlain by the dolomite member of the Tyson Formation.

13.3 STOP 3. Pull off road on right and walk west to sharp bend in road.

At bend in road is augen gneiss of the Mount Holly Complex. Walk back, northeast, and examine lithologies along road. The augen gneiss becomes very sheared near the contact with blue quartzite of the Mount Holly Complex. The blue quartzite is coarsely crystalline and contains pegmatites. Farther northeast is a conglomerate of the Tyson Formation interbedded with albite schist and carbonate-rich schist.

The same sequence of lithologies can be seen walking northwest from bend in road or going straight up cliff. The augen gneiss here is in the core of a small antiform.

Return to cars and continue west.

13.9 Low outcrops of augen gneiss in pasture north of road.

View of Pico and Killington Peaks to south

14.1 Turn south (left) onto Route 100.

15.9 Turn left into parking area for Kent Pond.

16.0 Stop 4. Park near east end of lot. Head south along shore to where Kent Brook flows into pond (approx. 50 m). Walk upstream to exposures of interbedded quartzite, marble, and calc-silicate rock of the Mount Holly Complex.

This package of interbedded quartzite, marble, and calc-silicate rock is very common on the broad terrace which runs north-south and is located east of Pico Peak and west of the Route 100 valley.

Return to cars and Route 100.

16.1 Turn south (left) onto Route 100.

16.3 Turn west (right) onto Route 4.

17.8 Sherburne Pass and Long Trail crossing. Cliffs on north side of road, called Deer Leap, are composed of cover rocks of the Tyson Formation. Some rather spectacular conglomerates are present near the top of the cliffs.

19.0 Beaver Pond on right side of road.

20.9 Turn right onto Old Turnpike Road, opposite Killington-Pico Motor Inn.

22.1 Pavement ends.

22.6 Road narrows, continue straight ahead.

23.2 STOP 5. Pull off to side of road.

Fine-grained dolomite of the Tyson Formation in road bed. Walk north 0.1 mile and turn east (right) into woods along obscure dirt track for approx. 45 m to abandoned quarry. Fine grained, buff-weathered dolomite.

Head due east 150 m to base of steep slope. Here is magnetite-rich albite schist of the Hoosac Formation. Upslope are layers of quartzite and quartz-rich schist. Further upslope are exposures of augen gneiss.

I interpret the augen gneiss here to be in thrust contact with the Hoosac Formation and to occupy the core of a synform (Fig. 4). The outcrop pattern on this unnamed hill is complicated by at least two sets of post-thrusting folds. The first set forms an east-closing, nearly recumbent synform. The second set of folds is more upright and open and is variably oriented.

Return to cars. Drive south to return to Route 4.

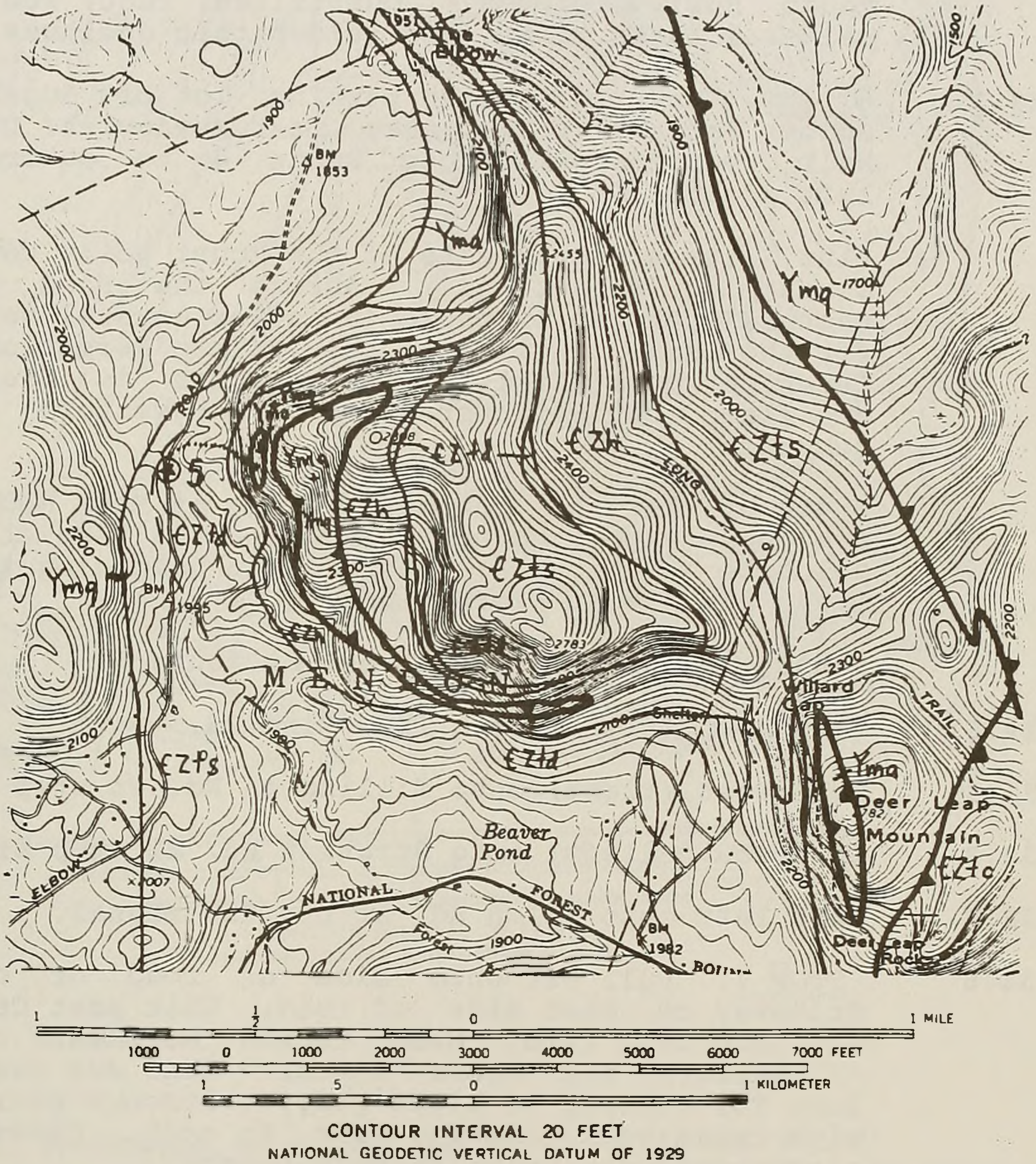

Figure 4. Photocopy of a portion of the Pico Peak 7 1/2' quadrangle showing the location of Stop 5. See Stratigraphy section in text for description of geologic units.

26.0 Turn west (right) onto Route 4.

27.1 Long outcrop on left of diverse lithologies in the Mount Holly Complex. Quartzites, rusty schists, calc-silicates rocks, and feldspathic gneisses.

28.3 STOP 6. Turn right into parking lot of Sugar and Spice Pancake House just past Meadowlake Drive. Walk 0.2 miles west along Route 4 to outcrop on left of road.

Blue, vitreous quartzite of the Mount Holly Complex containing pegmatites. Across the road is a pasture with no exposure (a rather unusual setting for the basal clastics of the Dalton Formation and Cheshire Quartzite). The pasture is probably underlain by carbonates of the western shelf sequence.

South of here on the west slope of East Mountain are good exposures of conglomerate, schist, and dolomite which I interpret as belonging to the Tyson and Hoosac Formations.

Return to cars and drive west on Route 4.

29.5 Turn south (left) onto Town Line Rd.

31.3 Turn west (right) onto Killington Rd. at stop sign.

32.3 Turn south (left) onto Stratton Rd. at stop sign.

32.9 Turn left onto Allen Rd. at traffic signal.

34.6 STOP 7. Pull off onto side of road or off of driveway on east side of road. Walk past Caboose and into tree farm. Head to the northeast corner of pasture and cross fence. Head due east and look for outcrop of light gray, vitreous quartzite with cross-beds showing tops to east. Cross-beds also present in dolomite beds nearby.

Quartzite beds are part of the Danby Formation. Farther east uphill are exposures of gray dolomite of the Clarendon Springs Formation and calcite marble of the Shelburne Marble.

Walk east through woods approx. 500 m to break in slope on west side of Bald Mountain. Outcrop of conglomeratic unit of the Tyson Formation.

Exposures of basement lithologies are present at the break in slope along strike to the north and south.

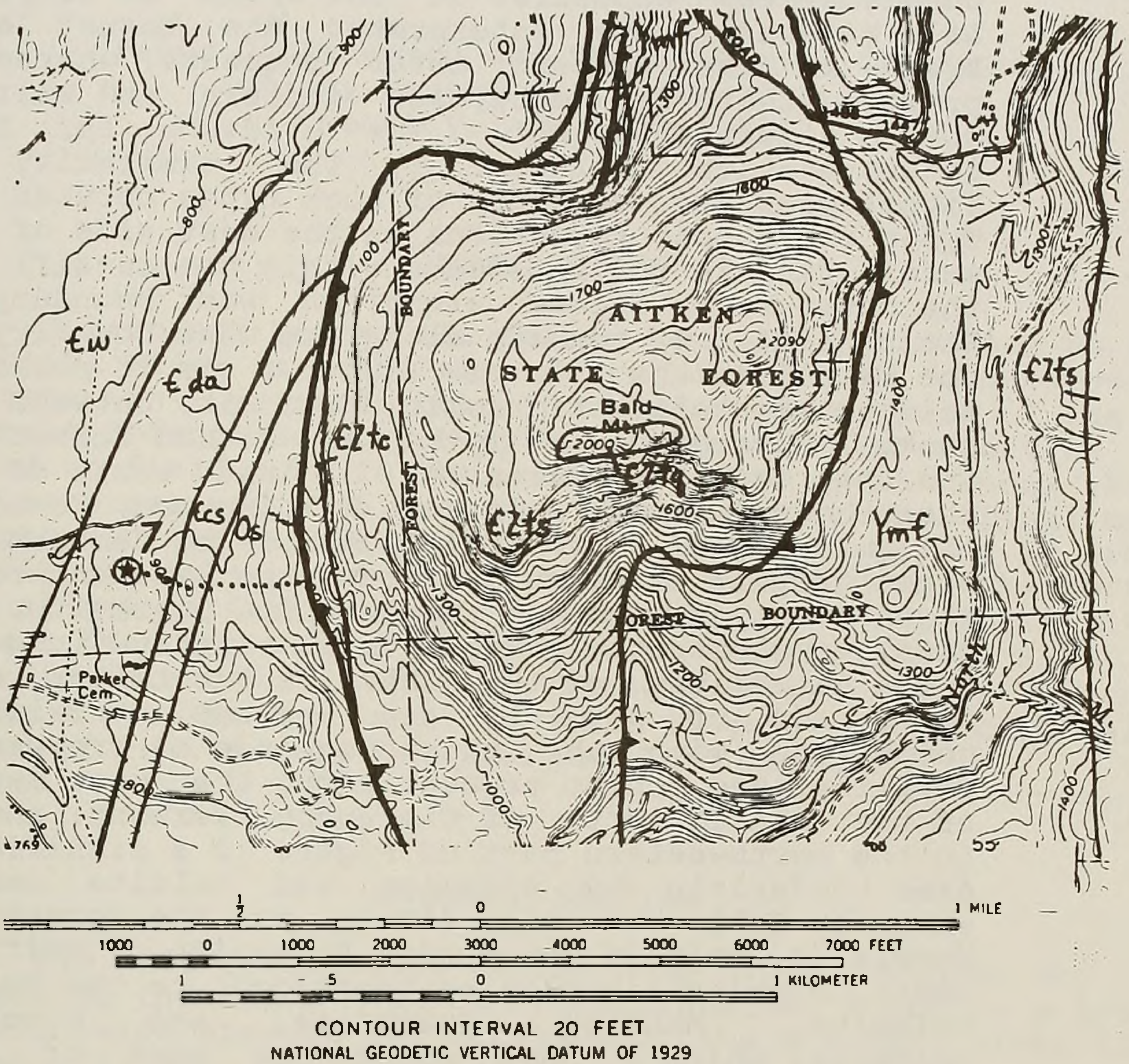

Figure 5. Photocopy of a portion of the Rutland 7 1/2' quadrangle showing the location of Stop 7. See Stratigraphy section in text for description of geologic units.

Brace (1953) mapped a thrust between the quartzite and marble outcrops in the pasture and the conglomerate exposures at the break in slope of Bald Mountain. He interpreted the thrust as a break in the western cover sequence, whereas I propose that it juxtaposes eastern and western cover sequence rocks. The evidence for this interpretation includes: 1) The similarity of lithologies and sequence of rock types between the Tyson and Hoosac Formations on the east side of the massif (and in thrust sheets within the massif) and the cover rocks exposed along the west boundary of the massif;. 2) nowhere along the west boundary of the massif in the area of Figure 2 is it possible to demonstrate stratigraphic continuity between the rocks I have mapped as Tyson and Hoosac Formations and the Cheshire Quartzite; 3) just south of the area shown in Fig. 2 in the Wallingford, Vermont, 15' quadrangle, where it is possible to demonstrate stratigraphic continuity from the basement-cover unconformity upward to the Cheshire Quartzite, the basal conglomerate grades very rapidly into the clean quartzites of the Cheshire Quartzite; only minor beds of phyllite are present, trivial in comparison with the thick sequence of graywacke, phyllite, and schist present along the west margin of the massif north of Clarendon, Vermont; and 4) in the northwestern part of Figure 2 a significant area underlain by dolomite and calcite marble shown by Doll et al. (1961) as the Forestdale Marble (a unit in the Mendon Formation of Whittle, 1894) contains lithologies identical to the Dunhan Dolomite, Monkton Quartzite, and Winooski Dolomite, which I have mapped as part of the western cover sequence. This stratigraphic reinterpretation, if correct, indicates that the Tyson and Hoosac Formations are in thrust contact with the western shelf sequence in this area.

Return to cars. Return to Route 4 by reversing directions back to stop 6. To go to Route 7 return to road, drive south 0.4 mi. and bear right where road forks. Turn right at intersection and drive west 0.8 mi. to Route 7.

END OF TRIP