Simplified Lithotectonic Synthesis of Pre-Silurian Rocks in Western New England

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INTRODUCTION

This bulletin is specifically designed to explain the maps and cross sections that appear on plates 1 and 2. It is a condensation of a much longer and comprehensive paper by Stanley and Ratcliffe (1984) where the comparable diagrams are more detailed and complete. We have prepared this simplified version as an aid to those geologists who are unfamiliar with the details of the Taconian geology of western New England. We hope it will be useful to people who are interested for any reason in the geological development of this region. Many of the ideas presented here are speculative and should be tested by future work. In particular, our emphasis on the tectonic assemblage of formations along and east of the basement massifs, and the inferred Taconian age of the assemblage should be tested by future field work, seismic study, and radiometric analysis.

Many of the ideas presented in this paper are intended to be provocative. We hope that our synthesis will encourage new studies and bring about a new focus of activity on such classic problems as the origin of the Taconic Mountains. Although we present alternative interpretations for the origin of many major structures in western New England, we realize full well that these problems are far from being solved.

MAJOR LITHOTECTONIC UNITS

The western part of central and northern New England can be divided into six major lithotectonic units that are marked by distinctive rock sequences (fig. 1). Although the boundaries between many of the units are shown as faults, this interpretation is in part speculative. Readers should understand that data bearing on these faults is limited and is only well constrained in a few areas. In Vermont, the thrust slices and most of the basal thrust faults are named for the dominant formation as mapped by Doll and others (1961). For example, the Underhill slice is largely made up of the Underhill Formation and is floored by the Underhill thrust.

1. Parautochthonous Green Mountain massif (YG), Lincoln massif (LI) and cover. Proterozoic Y gneiss of the Green Mountain-Lincoln massif forms a pachautochthonous basement upon which were deposited three sequences, 1) an Upper Proterozoic rift-clastic sequence, 2) a Lower Cambrian through Lower Ordovician carbonate platform, and 3) a Middle Ordovician limestone-shale back-arc basin sequence. Major unconformities separate sequence 1 and 3 from the underlying rocks. Basement rocks of the Waconic massif (Wn) and the Hudson Highlands, in New York and Connecticut are overlain by cover sequences 2 and 3 above. All of the above basement is considered to be correlatable with parautochthonous basement and cover sequence exposed in and around the Adirondack massif.

2. Taconic allochthons. For the purpose of discussion, the Taconic allochthons of Zen (1967) are divided into 3 groups by Stanley and Ratcliffe (1984). Groups 1 and 2 are shown as a single unit (horizontal lines) in figure 1. Group 3 slices, exposed west of the Green Mountain and Berkshire massifs, are shown by the horizontal line and stipple pattern. Group 1 slices were tectonically emplaced on soft unconsolidated Middle Ordovician rocks, and are underlain by welflisch deposits. These include the Giddings Brook and Sunset Lakes slices of Zen (1967) and several areas of predominately Austin Group Graywacke directly west of the Giddings Brook slice which Fisher (1977) interpreted as soft-rock slide masses. This group has the most complete stratigraphic range of any of the groups, extending from Late Proterozoic to Middle Ordovician, and presently occupy the greatest area. Group 2 slices consist of the Chatham, Rensselaer Plateau, Bird Mountain, Berlin Mountain, and Everett slices, which largely contain the lower part of the Taconic section with distinctive basaltic volcanics and associated graywackes. They are in fault contact with Group 1 slices. Fault slivers of the carbonate - siliciclastic platform in complex tectonic breccias are found along the contact of Group 1 and group 2 slices. Emplacement is thought to be premetamorphic.

Group 3 slices consist of the Dorset Mountain, the Greylock, the Canaan Mountain, and the June Mountain slices. These contain rock sequences that resemble the rocks in the Moosehead-Cavendish sequence that rest unconformably on 1 b.y. old basement of lithotectonic units 1 and 3. Symmetamorphic reclined folds and mineral lineations mark the fault zones. Westward displacement of the slices and their final emplacement postdated an earlier metamorphism in the Taconic slices and autochthon to the west.
3. Allochthonous Berkshire massif (Yb) and Proterozoic Y domes (Yc, Yc, Yc, Yc) of southeastern Vermont. The allochthonous Proterozoic Y basement of the Berkshire massif is separated from the eastern margin of the massif by four major thrust faults: the Hoosic thrust (HOT) to the west and the Hoosac Summit thrust (HST) - Middle Devonian fault to the east. The massif is internally imbricated along ten overlapping thrust faults, locally separated by slivers of cover rocks. The cover rocks consist of the massif's top carbonatic and siliciclastic rocks of the shelf sequence which locally grade upward into carbonate-siliciclastic rocks. The uppermost and easternmost part of the massif, the Hoosac Mountain, is unconformably overlain by rocks of late Precambrian or earliest Cambrian age that interfingers with the classic rocks of the western shelf sequence, but which continue as rocks of the eastern-facies belts of the same age. Basement gneiss in the domes of southeastern Vermont contain a cover similar to that found on the highest basement slice in the Berkshire massif. The domes are here considered to be allochthonous and comparable to the highest tectonic levels of the Berkshire massif.

4. Allochthonous Hoosac. Lithotectonic unit 4 consists of a narrow belt of Hoosac at the eastern margin of the Berkshire massif that extends northward as far as Middlebury and then southward into southwestern Connecticut, where it merges with the Manhattan terrane (Hall, 1980) south of figure 1. The sole of this unit is the Mugglesburg thrust, the Middlefield fault zone that formed from the Hoosic thrust (Norton, 1976) at the north end of the massif and leaves the Proterozoic Y-Hoosac contact and cuts upward into the Hoosac terrane. The Hoosac Summit thrust (Ratcliffe, 1979). Along its entire length the Hoosac Summit-Middlefield thrust zone exhibits mylonitic fabrics and is locally intruded by granite in thin sill-like sheets (Ratcliffe, 1975, Ratcliffe and Harwood, 1975). This unit represents the root zone for the youngest slice (unit 3) of the Taconic allochthons according to Stanley and Ratcliffe (1984).

5. Eastern Vermont slices. This complex of thrust slices is separated from underlying tectonic units to the west by the Hinesburg thrust (HT), the Underhill thrust (UT), the Whitcomb Summit thrust (WST), and the Camerons Line thrust (CLT) of figure 1. This zone of thrust faults forms a cryptic suture and condensed root zone for the Taconic allochthons in western Massachusetts and western Connecticut. As much as 660 km of displacement (plate 2) seems likely. The Underhill-Pinneepuck slice (HNS) and the Notch slice (HNS) disappear beneath the Rowe thrust zone (RTT) as the eastern Vermont slices are traced southward and, hence, represent part of a flattened duplex of Boyer and Elliott (1982).

In northern Vermont, the Hinesburg thrust (HT) has been shown to be the sheared out limb of a recumbent fold (Dorsey and others, 1983). This fold-thrust system represents the transition between the foreland imbricate thrusts of the St. Lawrence-Champlain valley (Champlain thrust, for example) and the highly-deformed metamorphic rocks of the Cambrian-Ordovician eugeoclinal section of the Green Mountain anticlinorium. The eastern limb of the anticlinorium contains ultramafic rocks. North of latitude 44° 33', the lower part of the carbonate-siliciclastic platform (Cheshire-Dunham sequence) is deposited on the underlying argillaceous rocks of the western part of the Underhill slice of figure 1 (Dorsey and others, 1983). This relationship indicates that the root zone for the Taconic allochthon is located to the east of the Hinesburg thrust within the Underhill slice at the latitude. Total displacement across the Hinesburg thrust zone at this latitude is estimated to be 10 km.

The Hinesburg thrust extends southward to the Lincoln area whose Tavvers (1992) and DiPietro (1993) have shown that it dies out in the overturned limb of the anticline cored by the eastern part of the Lincoln massif (YL, fig. 1). The U-shaped U-shaped topography of the Hinesburg thrust zone indicates that major thrust faults containing mylonites mark the northeastern border of the massif with cover rocks. These faults are now northward-bounded and along the western boundary of the Hinesburg Formation. We consider the base of the Underhill slice to mark the root zone for the Taconic slices in central Vermont.

Faults are interpreted to continue southward along the western contact of the Underhill - Pinney Hollow slice (UHS) and Rowe thrust zone (RTT) to the Massachusetts border. Here they join the Whitcomb Summit thrust (WST), which separates the allochthonous Hoosac Formation (horizontal line-stipple pattern, fig. 1) from the Rowe Schist to the east (Zen and others, 1983).

6. Core rocks of the domes of western Massachusetts and Connecticut (OZT). The eastern edge of the Eastern Vermont slices is shown as the basin contact between the Cambrian-Ordovician rocks and the Silurian-Devonian cover. Lithotectonic unit 6 appears from beneath the Eastern Vermont slices in the core of the Bristol, Collinsville, Granville, Goshen and Shelburne Falls domes (fig 1) as gneiss and amphibolite. These rocks are interpreted to be the tectonically thin western edge of the eastern volcanic arc-continent complex (Bronson Hill plate of Robinson and Wall, 1980) presently exposed along the Bronson Hill in central New England. The lower contact is interpreted to be the Bristol thrust. It is shown as such in the cross sections for western Massachusetts (Stanley, in Zen and others, 1983).

In northern Vermont and southern Quebec, the Ascut-Wedon sequence contains plutonic and volcanic rocks suggestive of an island arc (Gale, 1980; Hoar, 1981; Doolan and others, 1982). This sequence is located west of the Bronson Hill lineament and disappears beneath the Silurian-Devonian unconformity about 20 km south of latitude 45° 60' N. Although the relation of the Ascut-Wedon to the Bronson Hill is unknown at present, it may have been overridden by the Bronson Hill arc complex with the triple junction now buried beneath the Silurian-Devonian rocks to the east as suggested by Osberg (1978), for example. Gale (1980) and Hoar (1981) mapped the Coburn Hill thrust (CMT, fig. 1) along the western border of the Ascut-Wedon sequence in northern Vermont.

IMPORTANT STRATIGRAPHIC AND STRUCTURAL RELATIONSHIPS AMONG LITHOTECTONIC UNITS

The tectonic evolution of Vermont can only be understood by considering the tectonic framework for the development of western New England. The critical evidence for such reconstruction is drawn from stratigraphic, structural, and chronostratigraphic considerations. Although the details of these arguments are discussed more elaborately in Stanley and Ratcliffe (1984), the essence of these arguments are presented in the following paragraphs.

A major factor in the reconstruction is the paleogeographic site of the Taconic allochthons and their mechanism of emplacement. The history of this problem dates back to 1844, when Ebenezer Emmons suggested that the rocks of the Taconic Mountains represented a separate geological system. Since then heated debates have repeatedly occurred. During this century the debate has focused on whether the Taconic sequence was transported (allochthonous) or deposited in their present site (autochthonous). Critical evidence and arguments have been presented by Zen (1961, 1964, 1967, 1968, 1972), Berry (1962, 1968), Potter (1972), Ratcliffe (1969, 1970, 1975) and shown on the bedrock geological maps for Vermont (Doll and others, 1961); for Connecticut (Rogers, 1982); and for Massachusetts (Zen and others, 1983). These authors demonstrated the transported characteristic of the Taconics in agreement with earlier speculations of Ruedemann (1909) and Keith (1912, 1932), Friddle and Knope (1932), and Card (1945). Excellent summaries of these controversies are found in Rogers (1970, p. 75-90) and Zen (1967, p. 83-93).
More recent debate has focused on the mechanism of emplacement, notably, whether the Taconic allochthons were emplaced as gravity slides or as tectonic slices during the Silurian period. Immunological evidence suggests an early Si
lurian age for these allochthons. Z 1(I 1968, 1969) supports the hypothesis that some allochthons originated as gravity slides from source areas on top of the Green Mountain and Berkshire massifs well east of the carbonate platform. Synthesis was based on 1) the slope characteristic of the Taconic sequence; 2) the presence of flysch deposits beneath the leading edge of the Taconic allochthons; 3) the absence of a recognizable carbonate terrace east of the Green Mountain massif within the Eastern Vermont sequence; and 4) a stacking sequence for the Taconic allochthons in which the higher slices were emplaced after the lower slices. This age sequence suggested a process of diagenesis or unconformity.

Recent mapping in Massachusetts east of the Berkshire massif (Stanley and Ratcliffe, in Zen and others, 1983), in central Vermont (Tozers, 1982; D'Angelo, 1983), and in northern Vermont (Stanley and Roy, 1982; Stanley and others, 1984), however, has shown that the pre-Silurian euvelocenial rocks east of the Taconic Y massifs are not a coherent depositional sequence as previously suggested (Doll and others 1961), but are cut by numerous thrust faults which are thought to be largely Taconic in age. In southern Vermont, these slices east of the Berkshire Green Mountain massifs is permissible. Critical to the argument are: 1) the recognition by Stanley and others (1981) that the basin part of the carbonate siliciclastic platform (Lower Cambrian Cheshire-Dunham equivalents) in the Hoosac Formation unconformably overlies the eastern edge of the Green Mountain massif; and 2) the recognition that the Late Precambrian Pre-Olenellus clastic rocks (Hoosac of the Plymouth, Vermont section, section, and Dalton Formations, for example) form a coherent depositional cover that unconformably overlies the Precambrian basement of the Lincoln-Green Mountain-Berkshire massifs and domes of southeastern Vermont. These observations rule out the exposed Precambrian basement as a depositional site for the Taconic rocks and suggest that the root zone he located east of the Chester (Y) and Athens (Ya) domes (fig. 1).

Additional arguments that are important to the tectonic evolution of western New England were either discussed by Zen (1967, 1968, 1972) or Stanley and Ratcliffe (1984). These arguments are summarized below.

1. The rocks of the Taconic sequence in the Giddings Brook slice, which lack carbonate-bank deposits, are very similar to the Lower Cambrian through Lower Ordovician slope sections (Parker-Sweetsburg section) of Doll and others, 1961) in northwestern Vermont. These rocks have slightly shallower sequence than the deeper part of the carbonate siliciclastic platform (Dunham-Cheshire interval) to the clastic rocks of the Hoosac Formation demonstrates that the Giddings Brook slice deposits are east of the deeper part of the carbonate platform and graded downward and laterally into the older rift-clastic rocks.

2. The rocks of the basin and middle part of the Taconic sequence are similar to the rocks presently exposed in the Berkshire Underhill Formations in central and northern Vermont.

3. The basement rocks in the Precambrian Y domes in southeastern Vermont contain rocks that are lithically similar to those of the Green Mountain massif (Rosefield, 1972; Skelhan and Hegburn, 1972), and yield mineral and whole-rock ages in excess of 900 m.y. (Naylor, 1976). Granitic gneiss of probable intrusive origin (Tyrringham or Staford Granite Granite Gneiss are compositionally similar but are probably 1 b.y. old based on zircon and Rb/Sr whole-rock studies in the Berkshire massif (Ratcliffe and Zartman, 1969, 1975; McGraw and others, 1983) because they are very similar in composition and aspect. Their contact with the underlying basement formation is eastern in the Berkshire massif is considered to be a thrust fault, the Bristol thrust (Stanley, in Zen and others, 1983).

4. The serpentinitized ultramafic rocks in western New England are largely confined to the Hazen's Notch formation (HNS) and Row Basin Moteworth interval (Rowe thrust zone = RTE). This belt is continuous with the fragmented ophiolite sequence of Quebec and, hence, the ultramafic rocks are thought to be remnants of oceanic crust (Laurent 1975, 1978; St. Julien and others, 1978; Douglas and others, 1980). In northern Vermont, these rocks occur as silvers along thrust faults and have been interpreted as the root zone of the fault and, therefore, are regarded to be remnants of an older accretionary wedge sequence which has been repeatedly deformed during the Taconic orogeny (plate 2).

5. The regionally continuous Moteworth-Hawley sequence (OH-0h) consists of two quite distinct sequences: the light gray, well-bedded quartzites, granofels, and schists of the Taconic Moteworth Formation and the black, carbonaceous schists and fine-grained cherts of the Hawley Formation. Although both units contain mafic volcanic and volcanogenic rocks, they are more abundant in the Hawley Formation. The Moteworth also contains graded beds and debris-flow deposits (Badger, 1979). The rocks of the Moteworth Formation are considered by us to represent a forearc basin deposit in which the quartzites, quartz-rich granofels, and debris flows were derived from the emerged parts of the western accretionary wedge (Rowe thrust zone). The mafic, felsic, and volcanogenic rocks were derived from an eastern volcanic arc associated with either the Ascut-Weddon belt to the north or the larger, more continuous Bronson Hill volcanic arc complex to the east.

The Hawley Formation in figure 1 and the equivalent Partridge Formation to the east were deposited in a rift that trended north-south. The Mesozoic region to the volcanic arc which is presently represented by the rocks of the Bronson Hill anticlinorium. Since which unconformably overlies the â" the anticlinorium (Robinson, in Zen and others, 1983) and, in places, interfinger with volcanogenic rocks of the Berkshire formation, are largely equivalent to the dark-gray to black Middle Ordovician shales that grade westward into bedded limestone and unconformably overlie the carbonate and siliciclastic rocks of the platform. They are included as OCP of the Middle Ordovician sequence on the platform and in the Taconic allochthons is thought to have formed in a separate back-arc basin or eugeosyncline between the accretionary wedge to the east and the North American craton to the west.

7. The gneisses and amphibolites (OSG) in the domes west of the Mesozoic basin are correlated with the rocks of the Bronson Hill anticlinorium (Robinson and others, 1978) in the Berkshire massif (Bemis, 1983) because they are very similar in composition and aspect. Their contact with the underlying Moteworth Formation is eastward in the Berkshire massif. The area is considered to be a thrust fault, the Bristol thrust (Stanley, in Zen and others, 1983).

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The west-to-east stacking sequence among the Taconic slices toward the nearest the hinterland (group 3 slices, horizontal lines with stippleis). The oldest slices are on the bottom (Giddings Brook or Valentine, for example) and are located toward the foreland. This arrangement is opposite to the more common "piggyback" sequence in which the youngest of the slices are on the bottom and are closest to the foreland. The development of the Taconic slices toward the hinterland is required because of the presence of silvers of carbonate platform rocks between many of the slices and 2) the presence of a Taconic deformed Sanborn fault-zone schistosity along group 3 thrust faults. This schistosity replaces an older schistosity. Metamorphic fabrics are absent along the older thrust faults in the Taconic allochthons to the west but are present to the east along the Hoosac Summit thrust (HST) and the Middlefield fault zone (MFF). The critical data for these relations are described in Zen and Ratcliffe (1966), Potter (1972, 1979), and Ratcliffe (1974a, 1974b, 1974c, 1979) and are shown on the Bedrock Map of Massachusetts (Zen and others, 1983).

EVOLUTION OF VERMONT DURING THE TACONIC OROGENY AS RECONSTRUCTED FROM RETRODEFORMED SECTIONS FOR WESTERN NEW ENGLAND

Although the following discussion emphasizes the Taconic orogeny, the reader must realize that severe Acadian deformation, which pervaded much of New England, has overprinted this older geology. For example, cross section B-B' (fig. 3) shows that the Precambrian through Devonian section is unconformably folded over the Champlain dome. These folds and the accompanying metamorphic events are the western front of a series of regional west-striking fold nappes that dominate the Acadian geology of the Bronson Hill anticlinorium (Thompson and others 1968; Robinson, 1979; Robinson and others, 1979; Robinson, in Zen and others, 1983), and become more extensive in southern Massachusetts and Connecticut. In Vermont the intensity of the Acadian orogeny diminishes to the north. Although we suggest that much of the large-scale tectonic fabric of western New England is Taconic, the direct evidence for this age assignment is uncertain at present. Subsequent extension during the Mesozoic produced normal faulting throughout the region but their influence on our reconstruction is very minor with the exception of the large lenticular faults in central New Hampshire along the Vermont - New Hampshire border (cross section C-C', plate 2).

The evolution of Vermont during the Taconic orogeny is described by studying the sequence of retrodeformed cross sections 1 through 8 (fig. 1). Cross section 1 (C-C') shows the geology as it is interpreted to exist today from the Bronson Hill anticlinorium in north-central Massachusetts to Albany, New York (Ratcliffe and Stanley in Zen and others, 1983). Cross sections 2 through 8 successively deform the geology shown in cross section 1 to produce the pre-Taconian configuration depicted in cross section 8. The west to east expansion resulting from reversing movement on major faults and unfolding of major folds is shown between each cross section. For example, cross section 2 has been extended by 15 km to produce cross section 3. This extension is produced by moving point 1 on the upper plate of the Champlain thrust (CT) 15 km to the west and point 2 on the lower plate of the Champlain thrust 15 km to the east. Cross section 3 coincides with point 2 on the lower plate. The folding associated with this event is also eliminated so that cross section 3 is longer and less folded. Cross sections 1-7 are aligned along a vertical reference mark so that the extension in each section can be visually assessed by the position of the Bronson Hill anticlinorium (OD). Note the scale change between cross sections 5 and 6. This palinspastic reconstruction provides a relatively accurate mapping of the hypothetical geology of a mountain belt. It begins with what is known and progresses backward in time to stages where our knowledge of the geology is less certain. Each step of the way is guided by existing evidence or our interpretation of that evidence.

The tectonic evolution of western New England, therefore, can be visualized by studying cross sections 8 through 1 which begins during Early Ordovician and Early Middle Ordovician when compression between the North American and Bronson Hill plates had developed an accretionary wedge to the east at an undetermined distance from the North American continental margin. Total shortening, beginning with the westward emplacement of the Giddings Brook slice, is in the order of 655 km. This value does not include the shortening associated with multiple generations of cleavage reported for these rocks. If a conservative estimate of 50 percent shortening is assumed for this process, then the total shortening would be in the order of 1,000 km. This value is reasonable if one considers the terminal velocity of plate subduction to be 60 km/my to 90 km/my (Farquah and Uyeda, 1975, p. 178). According to Pfitzner and Ramsay (1982, fig. 1b), the time span for deformation in mountain chains is between 1-30 million years with a common rate of 1-3 million years. In the last 50 million years, the collision between the western Philippine plate and the Eurasian plate has covered a time span of 15 million years (Suppe and others, 1981). The processes and plate geometry that have led to the formation of Taiwan are analogous to those that took place in western New England during the Taconic orogeny. Therefore, we use a figure of 15 million years for the shortening event that has taken place just before the emplacement of the allochthons and ending with the final displacement of the sialic slices. Thus, the total shortening during the Taconic is 1,050 km (70 km/my, Semo, 1977) which basically agrees with the displacements arrived at by the retrodeformational process.

In developing the diagrams on plate 2, the following relations emerged:

1. Reversing the sequence from cross sections 1 through 8 required considerable restoration of material. This material was originally eroded from the cross sections during each stage in the evolution of the western margin. The restored material has been assigned to the plate eroded from cross section 4 as it evolved to cross section 3, and so on. Thus, each layer or phase of cross section 4 (horizontal lines) appears on top of Group 3 slices (horizontal lines with stipple) in cross section 4. Evidence for this relationship is not present today because of extensive post-Taconian erosion. This example highlights that much of the evidence of past configurations and events has been destroyed in the very processes that have been important during the evolution of western New England. Furthermore, it illustrates how uncertain our reconstructions are despite the constraints of palinspastic (retrodeformational) analysis.

2. The topographic profiles that are assigned for the "Taconic Mountains" during their evolution are realistic if we consider topographic profiles for active converging plate margins and the maximum elevation for Taiwan today is 13,000 ft (3940 m) with an annual uplift rate of 5 mm/yr (Peng and others, 1977). Recent analysis of the topography in Taiwan relative to its converging rate of 70 km/my has shown that the topography is balanced by the rate of erosion, which is in turn influenced by the tropical climate in Taiwan (Suppe, 1981). The same type of configuration is shown in the cross sections for the western margin of New England which is comparable to Taiwan in the Middle Ordovician (Bambach and others, 1980, fig. 6). Thus, the cross sections are in a dynamic state, implying that the figures do not show only the evolution of the margin but also depict the topographic configuration and, hence, aspects of the evolution that might not be otherwise apparent.
3. An important aspect of the inferred topography is the morphological expression of active thrust faults. These features are shown as steep slopes where they intersect the earth's surface. Some of these slopes may have been subaerial (Whitcomb Summit thrust, WST) whereas others were subaqueous (Giddings Brook thrust, GBT). The major thrust zone along the advancing front would form olistostromal deposits (O.D.) in basins on the lower plate. These deposits were largely ephemeral but some were preserved as Middle Devonian (Middleport) facies - a leading edge of and beneath the Giddings Brook slice. Elsewhere, they would disappear as the higher basins were eroded. The highest restored cross sections certainly emphasize the possibility that the material in the Austin Glen could have been recollected many times from original source and, hence, have nothing to do with the silices and their present stacking order.

4. One of the more subtle aspects of the present cross sections is the degree to which the North American crust has responded to loading during westward imbrication. This can be demonstrated by a reverse along eastward-dipping thrust zones in the younger cross sections. For example, in preparing cross section 3 of the Middlefield-Hoosac thrust zone (HST-MFZ) in section 4 is moved eastward. This displacement results in the upper part of the section ending up far below sea level. To correct for this error, the dip of the thrust zone is reversed in the retrodeformation process so that the Bronson Hill Arc Complex and associated accretionary wedge in section 5 are in a reasonable position near sea level. In short, reversing the collisional process unloads the eastern part of the North American crust causing it to rise toward sea level (compare cross sections 2 and 8).

5. The emplacement of the Taconic slices (cross sections 7, 6, and 5) is shown to result from continued, progressive horizontal compression and gravity spreading during westward loading on the North American plate and the Bronson Hill plate. Gravity sliding is not employed for any of the slices. During compression, the wedge-shaped volume of continental margin sediments thickened. This raised the center of gravity of the mountain range and provided an added lateral force to the existing horizontal compression of plate collision. The dominant movement is east-over-west, although important motion in the opposite direction may have occurred. The cross sections show that the Taconic slices developed from a single large coherent slice (cross section 7) in which the eastern part broke up into the smaller slices of Group 2. As these slices moved over the western part of the original Giddings Brook slice (cross section 6), slivers of the carbonate platform were dragged up along these fault zones.

6. During emplacement, the Taconic slices are shown as an internally deforming package of slices that moved over and deformed the carbonate platform. As a result, the frontal parts of all the active thrust faults were continually accreting material between adjacent plates, as olistostromal deposits (O.D.) forming on the steepened surface. This process was particularly active along the leading edge of the Giddings Brook thrust (GBT) and lead to a complex history of accretionary wedge sections of autochthonous middle Ordovician shales, Giddings Brook rocks, and recycled olistostromal deposits.

7. The Rowe thrust zone (RTZ) is shown as the fragmented remains of an older stage of the accretionary wedge - a stage that originally developed from oceanic sediments and was extended more and more along the slope-section as the North American crust moved eastward into the subduction zone. During this time, latest Ordovician and Silurian olistostromal rocks were sheared off and incorporated into the accretionary wedge. The highly fragmented and tectonized rocks were then moved westward as a more or less coherent unit along the Giddings Brook Thrust. The part of the former Thompson Thrust that we see today in the northern Massachusetts cross section (cross section 1, pl. 2).

8. We have also attempted to incorporate the Taconian metamorphic history into the retrodeformed cross sections. Evidence of the polymetamorphic events has been described by a number of workers during the last 15 years (Laird and Albee, 1981a, 1981b; Laird and others, 1984). Recently much of this information has been synthesized by Gutter and others (1984) who suggest that the metamorphism be recognized in western New England: 1) an older high-to-medium-high-pressure/low-temperature metamorphism (M2-L.G., pl. 2) and a second high-grade metamorphism (M2-H.G., pl. 2). An interpretation of these proposed events is shown in the restored cross sections. The older event (M1) must have occurred in the subduction zone sometime between cross sections 6 and 7 before the slope-rise sequence was emplaced onto the continent as the Taconic slices. These higher pressure rocks were then displaced westward as a series of thrust slices so that they now rest tectonically on lower pressure and lower temperature rocks as, for example, along the Underhill thrust in Vermont. A younger low-grade Barrovian metamorphism (M2-L.G.) extended farther to the west (cross section 6, for example) and overprinted the older metamorphic event. The high-grade metamorphism developed with the emplacement of Granville (GBT), Willard, and Hopeville (stipples) and culminated with the westward transport of the sialic slices. The position of the metamorphic isograds is shown in the upper sections after peak metamorphism is then controlled by subsequent erosion and the relative motion of the respective slices.

9. In cross sections 3–7, the black shales of the Middle Ordovician are shown in many as four separate basins. Two of these basins, the volcanic arc and the other between the continent and the wedge, persist through all the other cross sections. The basin between the accretionary wedge itself. The age of the black shales, therefore, were not strictly contemporaneous although they are commonly considered as such. For example, the black shales in the basin between the accretionary wedge and the continent are probably older than those to the east or west. Shales accumulated here first are now represented by the Normanskill shale in the Taconic slices. During Middle Ordovician time, these shales transgressed westward over the carbonate platform. To the east, a smaller basin developed in the forearc region as the accretionary wedge grew in size. Cross Sections 4–8 clearly show that the Middle Ordovician slice of the Monticello)). Normanskill, Hollywood and Partridge were probably not deposited in one continuous basin and, therefore, may not be equivalent in a strict stratigraphic sense.

Tectonic summary

The evolution of western New England is depicted in plate 2 beginning with cross section 8 and ending with cross section 1. The earliest compressional event for which we find evidence is the intense imbrication of ocean crust-rise material represented by the Rowe thrust zone (RTZ) and its northern equivalents in the serpentinite belt in northern Vermont. This zone developed in an early accretionary wedge offshore of the continental margin of North America (cross section 8). How much displacement had occurred before this time is unknown. Although cross section 8 represents the plate configuration some time in the early Middle Ordovician (perhaps granulite zone), it is clear that the first stage in the emplacement of the Taconic slices, the beginning of subduction along the western edge of the Bronson Hill plate is uncertain but probably started in the late Ordovician. The Moretown Formation is here interpreted as a forearc basin deposit receiving material from the eastern volcanic arcs and some emerged parts of the western accretionary wedge producing such debris as the Umbrella Hill Conglomerate.
Prior to the time depicted in cross section 8, coarse clastic rocks (C3e) accumulated in active, Late Precambrian pull-apart basins to west of the seaward albite-rich clastic rocks of the Hoosac and equivalent formations were deposited in similar, but posterior positions. The carbonate rocks and quartz-feldspar clastic rocks of the carbonate platform which, in turn, grade eastward into deeper marine siltstones, slates, and turbidites of the Taconic sequence in the slope-rise region. Later, Middle Ordovician black shales were deposited in a large back-arc basin between the accretionary wedge and the carbonate bank and a smaller one to the east in the forearc region. We speculate that deposition of the shales began in the slope-rise region (Taconic sequence) and gradually prograded westward over the carbonate platform to form the configuration of cross section 8. In this view, the Middle Ordovician pre-shale unconformity likely formed over the outer swell as the eastern margin of the North American plate approached the subduction zone. The total width of the cross section is unspecified because the location of the subduction zone to the east is unknown.

Subsequent movement of the continental crust into the subduction zone incorporated slope-rise material of the Taconic sequence into the accretionary wedge and displaced it westward onto the eastern edge of the carbonate platform in the form of the Giddings Brook slice. At this time, the more deeply deformed and metamorphosed high-grade metamorphic rocks overlapped the eastern part of the Giddings Brook slice. To the east, the younger part of the accretionary wedge, largely made of tectonized micas (RT2), emerged to form a non-volcanic arc with slide deposits containing sediment in the subduction basin. Middle Ordovician shales are shown in three separate marine basins; one in the eastern forearc region; the second between the non-volcanic arc (RT2) and the emerged Taconic slices; and the third along the exoecysiscline or back-arc basin to the west of the Taconic slices. Consequently, two non-volcanic arcs developed as the accretionary wedge expanded and encroached the continental margin sediments of the Taconic sequence of cross section 8. A smaller intermontane basin with olistostromal deposits (O.D.) is shown in front of the Pinney Hollow and Hazen's notch slices because these slices were probably active at this time.

With continued compression, the deeper and more eastern part of the slope-rise terrane failed (dashed faults, cross section 7) and overrode the western part of the Taconic slice to produce the configuration of cross section 7. Continued deformation during failure deformed the carbonate platform and silvers of the carbonate platform (OC2) were ripped up and emerged along the thrust faults (faults slices). This process continued during westward movement of the Taconic slices (cross sections 8 and 9). Subsequent westward movement of the Taconic slices moved onto the continental margin sediments of the Taconic sequence. To the east, the emerged part of the accretionary wedge of cross section 7 had been eroded to form a large forearc basin, although small non-volcanic arcs may have existed elsewhere along the accretionary ridge.

Subsequently, low-grade Barrovian metamorphism (M2-L.G) developed as the eastern margin of North America was loaded and thinned by the Taconic slices. This thermal event overprinted the older higher pressure subduction-zone event and strain softened the eastern margin. The subsequent deformation foliated the older thrust faults and the underlying platform.

Continued overlapping of the North American and Bronson Hill plates displaced the basal albite-rich metamorphosed eastern facies (allochthonous Hoosac Formation, AHS) of the basal platform clastic rocks westward as Group 3 slices (horizontal lines and stippled, cross section 9). With them were carried the basal thrust faults of Group 2 and all horizontal contacts. Fragments of the carbonate platform were undoubtably incorporated along Group 3 thrust faults at this time. Subsequent westward movement (M2-L.G) accounted for deformation of the older (M2-L.G.) metamorphic fabric and produced recrystallized micas that were stretched out in the new thrust-related foliation. The Group 3 Taconic slices are shown in cross section 9 as the weakest continuation of the volcanic-bearing allochthonous Hoosac, whose basal thrust (M2-HST) now forms the eastern border of the Berkshire massif. Again, we believe that basal thrust faults (PHT, MHT, WST) of the Eastern Vermont slices were active. As seen in cross sections 7 through 10, the Hazen's Notch, Pinney Hollow, and Underhill synclines formed, overlapped by continued motion of the Whitcomb Summit thrust (WST).

As a result they have been totally sheared out in the latitude of northern Massachusetts where the River's mouth thrust zone (RT2) is in direct contact with the allochthonous Hoosac (AHS).

Continued entry of the North American plate into the subduction zone was accompanied by increasing temperature which steepened the Barrovian isograds (cross sections 4, 3, and 2). Strain softening of the sialic crust resulted in failure of the North American crust along many thrust faults. These are represented by the 10 slices of the Berkshire massif and the more coherent and less ductile slices of the Housatonic and Green Mountain massifs to the west. The enlarged thickness of the eastern margin of North America at this time may have resulted in partial melting of the sialic and subjacent crust and subsequent intrusion of granite, diorite, and gabbro. These rocks are found today along the eastern side of the Berkshire massif and to the south in western Connecticut and eastern New York. The large size and lesser density of the sialic slices compared to the oceanic crust was probably the main factor in stopping the collision process (Chapple, 1973). The emplacement of the Green Mountain and Housatonic slices produced the Mountain anticlinorium and its western counterpart, the Middlebury synclinorium as such basal thrust faults associated to the tip-up thrust of the Algonquin orogen (cross section 7).

Subsequent uplift, erosion, deposition of Silurian and Devonian rocks, Acadian deformation and metamorphism, and Mesozoic rifting (section 5) resulted in the configuration of cross section 1. The degree to which Alleghanian deformation contributed to this cross section is unknown, although it is presently considered to be very minor.

ACKNOWLEDGMENTS

Although it is impossible to acknowledge properly all the geologists that have contributed to our understanding of western New England, we would like to thank R. A. Zen, John Bird, Donald Potter, David Harwood, Norman Hatch, Stephen Norton, Philip Osberg, Leo Hall, Peter Robinson, John Sutter, Barry Doolan, and John Suppe for their helpful discussions and their willingness to share data and thoughts with us. Although the interpretations presented in this paper are our own, we do acknowledge that many of these ideas may have nucleated from these mutual discussions. The errors or incorrect interpretations are our responsibility. The material in this bulletin has been simplified and greatly condensed from Stanley and Raitt, 1984. The critical review of that paper by Norman Hatch, Leo Hall, Philip Osberg, Harold Williams, Robert Hatcher, and Williams Thomas have indirectly contributed to the clarity of this bulletin. Becky Dorsey drafted the figures and helped with the final editing and publication process. Ragan Cary Barlett drafted figures 1 and 4. Charles Raitt reviewed the bulletin. Field work was supported by the U.S. Geological Survey (Stanley and Raitt) and the Vermont Geological Survey (Stanley). Drafting and printing was funded by U.S. Department of Energy Grant DE-FG02-83ER13166 which covered the cost of the Geological Survey. Any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the Department of Energy.
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