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 unfamilar 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 for this 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 (Yl) and cover. Proterozoic Y gneiss of the Green Mountain-Lincoln massifs forms a parautochthonous basement upon which were deposited three sequences, 1) an Upper Proterzoic rift-clastic sequence, 2) a Lower Cambrian through Lower Ordovician carbonate - siliciclastic shelf sequence, 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 Housatonic massif (Yh) 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 correlative with autochthonous 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 wildflysch deposits. These include the Giddings Brook and Sunset Lake slices of Zen (1967) and several areas of predominantly Austin Glen 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 Z 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 Hoosac-"Cavendish" sequence that rest unconformably on 1 b.y. old basement of lithotectonic units 1 and 3. Synmetamorphic 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, Ya, Yj, Yw) of southeastern Vermont. The allochthonous Proterozoic Y basement of the Berkshire massif is separated from its adjoining lithotectonic units 1 and 4 by major thrust faults: the Hoosic thrust (HoT) to the west and the Hoosac Summit thrust (HST) - Middlefield fault zone (MFZ) to the east. The massif is internally imbricated along ten overlapping thrust faults, locally separated by slivers of cover rocks. The western half of the massif is covered by basal clastic rocks of the shelf sequence which locally grade upward into carbonate-siliciclastic rocks. The uppermost and easternmost slice in the massif on Hoosac Mountain is unconformably overlain by rocks of late Precambrian or earliest Cambrian age that interfingers with the clastic rocks of the western shelf sequence, but which are transitional to 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 Middletown, Vermont, and widens southward into Connecticut, where it merges with the Manhattan terrane (Hall, 1980) south of figure 1. The sole of this unit is a major thrust, the Middlefield fault zone that Norton (1976), mapped along the eastern margin of the Berkshire massif. At the north end of the massif, the fault leaves the Proterzoic Y-Hoosac contact and cuts upward into the Hoosac terrane as 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 fault represents the root zone for the youngest slices (group 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-Pinney Hollow slice (US-PHS) and the Hazens Notch slice (HNS) disappear beneath the Rowe thrust zone (RTZ) as the Eastern Vermont slices are traced southward and, hence, resemble part of a flattened duplex of Boyer and Elliot (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 44^0 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 relation indicates that the root zone for the Taconic slices 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 where Tauvers (1982) and DiPietro (1983) 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). More importantly, these geologists have shown that major thrust faults containing mylonites mark the northeastern border of the massif with cover rocks. These faults extend northward beneath and along the western boundary of the Underhill 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 (US-PHS) and Rowe thrust zone (RTZ) 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 (OZ?). The eastern edge of the Eastern Vermont slices is shown as the basal 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 Hall, 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 Ascot-Weedon 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 anticlinorium and disappears beneath the Silurian-Devonian unconformity about 20 km south of latitude 45^0 00'. Although the relation of the Ascot-Weedon 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 (CHT, fig. 1) along the western border of the Ascot-Weedon 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 a reconstruction is based on stratigraphic, structural, and chronological considerations. Although the details of these arguments are elaborated more fully 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, 1974a, b, c, 1975) and shown on the bedrock geological maps for Vermont (Doll and others, 1961); for Connecticut (Rodgers, 1982); and for Massachusetts (Zen and others, 1983). These authors demonstrated the transported character of the Taconics in agreement with earlier speculations of Ruedemann (1909), Keith (1912, 1932), Prindle and Knopf, (1932), and Cady, (1945). Excellent summaries of these controverses are found in Rodgers (1970, p. 75-90) and Zen (1967, p. 83-93).

More recent debate has focused on the mechanism of emplacement, namely, whether the Taconic allochthons were emplaced as gravity slides or as horizontally - compressed imbricated slices. Zen (1967, 1968, 1972) suggested that the allochthons originated as gravity slides from a source area on top of the Green Mountain and Berkshire massifs well east of the carbonate platform. This interpretation was based on 1) the slope-rise character of the Taconic sequence; 2) the presence of wildflysch deposits beneath the leading edge of the Taconic allochthons; 3) the absence of a recognizable root zone east of the Green Mountain massif within the Eastern Vermont sequence; and 4) a stacking sequence for the Taconic slices in which the higher slices were emplaced after the lower slices. This age sequence suggested a process of diverticulation or unpeeling.

Recent mapping in Massachusetts east of the Berkshire massif (Stanley and Ratcliffe, in Zen and others, 1983), in central Vermont (Tauvers, 1982; DiPietro, 1983), and in northern Vermont (Stanley and Roy, 1982; Stanley and others, 1984), however, has shown that the pre-Silurian eugeoclinal rocks east of the Precambrian 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 Taconian in age. Thus a root zone for the Taconic slices east of the Berkshire and Green Mountain massifs is permissible. Critical to the argument are: 1) the recognition by Thompson (1972) and Skehan (1961) that the basal 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 Precambiran-pre Olenellus clastic rocks (Hoosac of the Plymouth, Vermont section, Pinnacle, 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 be located east of the Chester (Yc) 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 sequence (Parker-Sweetsburg section of Doll and others, 1961) in northwestern Vermont. The fact that this sequence grades downward through the basal part of the carbonate - siliciclastic platform (Dunham-Cheshire interval) to the clastic rocks of the Pinnacle Formation demonstrates that the Giddings Brook slice was depositied east of the main part of the carbonate platform and graded downward and laterally into the older rift-clastic rocks.

2. The rocks of the basal and middle part of the Taconic sequence are similar to the rocks presently exposed in the Pinnacle and 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 (Rosenfeld, 1972; Skehan and Hepburn, 1972), and yield mineral and whole-rock ages in excess of 900 m.y. (Naylor, 1976). Granitic gneiss of probable intrusive origin (Tyringham or Stamford Granite Gneiss) are common to all areas and are probably 1 b.y. old based on zircon and Rb/Sr whole-rock studies in the Berkshire massif (Ratcliffe and Zartman, 1976). Recent mapping in the Berkshire massif (Ratcliffe, 1969, 1975; Ratcliffe and Harwood, 1975; Ratcliffe and Zartman, 1976; Harwood, 1975; Norton, 1975, and Ratcliffe, in Zen and others, 1983) and seismic studies across southern Vermont (Ando and others, 1983) indicate that the Precambrian Y basement is cut by imbricate thrust faults. Rb/Sr analysis on intrusive granite that cuts several of the faults on the east side of the Berkshire massif suggest a Taconian age for these faults. Although Stanley and Ratcliffe (1984) interpret these faults to be Taconian in Vermont, direct fabric and radiometric information to this effect is not available at present.

4. Group 3 Taconic slices are very similar to the allochthonous Hoosac Formation of western Massachusetts and western Connecticut and, therefore, are thought to root beneath or within this sequence. They are shown by the horizontal lines with stipples west of the Green Mountain and Berkshire massifs in figure 1.

5. The serpentinized ultramafic rocks in western New England are largely confined to the Hazens Notch Formation (HNS) and Rowe-basal Moretown interval (Rowe thrust zone = RTZ). 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, 1976; Doolan and others, 1982). In northern Vermont, these rocks occur as slivers along thrust faults and they are interpreted to occur in this way in western Massachusetts (Stanley and others, 1984). Based on this evidence, the Rowe thrust zone and the Hazens Notch slices of figure 1 are considered to be remnants of an older accretionary wedge sequence that has been repeatedly deformed during the Taconian orogeny (plate 2).

6. The regionally continuous Moretown-Hawley sequence (Om-Oh) consists of two quite distinct sequences - the light gray, well-bedded quartzites, granofels, and schists of the Moretown 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 Moretown also contains graded beds and debris-flow deposits (Badger, 1979). The rocks of the Moretown Formation are considered by us to represent a forearc basin deposit in which the quartzites, quartz-rich granofels, and debris flows where 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 Ascot-Weedon 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 relatively shallow, stagnant basin that extended across the forearc region to the volcanic arc which is presently represented by the rocks of the Bronson Hill anticlinorium. Here they unconformably overlie older rocks exposed in the domes of the Bronson Hill anticlinorium (Robinson, in Zen and others, 1983) and, in places, interfinger with volcanogenic rocks (Cobble Mountain Formation, Oc, fig. 1). The Hawley and Partridge Formations are largely equivalent to the dark-gray to black Middle Ordovician shales that grade westward into bedded limestones and unconformably overlie the carbonate and siliciclastic rocks of the platform. They are included in OCp of figure 1. Similar shales are found in the Taconic sequence. The Middle Ordovician sequence on the platform and in the Taconic allochthons is thought to have formed in a separate back-arc basin or exogeosyncline between the accretionary wedge to the east and the North American craton to the west.

7. The gneisses and amphibolites (OZ?) in the domes west of the Mesozic basin are correlated with the rocks of the Bronson Hill anticlinorium (Robinson and Stanley, in Zen and others, 1983) because they are very similar in composition and aspect. Their contact with the underlying Moretown Formation is exposed in the Bristol dome (B, fig. 1) and is considered to be a thrust fault, the Bristol thrust (Stanley, in Zen and others, 1983).

8. The west-to-east stacking sequence among the Taconic slices is arranged with the youngest slices on top nearest the hinterland (group 3 slices, horizontal lines with stipples). The oldest slices are on the bottom (Giddings Brooks slice, for example) and are located toward the foreland. This arrangement is opposite to the more common "piggyback" sequence in which the youngest thrust slices are on the bottom and are closest to the foreland. The development of the Taconic slices toward the hinterland is required because of two important observations, namely: 1) the presence of slivers of carbonate platform rocks between many of the slices and 2) the presence of a Taconian synmetamorphic fault-zone schistosity along group 3 thrust faults. This schistosity deforms an older schistosity. Synmetamorphic 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 (MFZ). 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 TACONIAN OROGENY AS RECONSTRUCTED FROM RETRODEFORMED SECTIONS FOR WESTERN NEW ENGLAND

Although the following discussion emphasizes the Taconian orogeny, the reader must realize that severe Acadian deformation, which pervades 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 recumbently folded over the Chester dome. These folds and the accompanying metamorphic events are the western front of a series of regional west-facing 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 Taconian, the direct evidence for this age assignment is uncertain at present. Subsequent extension during the Mesozoic produced normal faults throughout the region but their influence on our reconstuction is very minor with the exception of the large listric faults in central New England which extend northward along the Vermont - New Hampshire border (cross section C-C', plate 2).

The evolution of Vermont during the Taconian orogeny is described by studying the sequence of retrodeformed cross sections on plate 2. 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 2-8 successively undeform 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 major folds is shown between each cross section. For example, cross section 2 has been extended by 35 km to produce cross section 3. This extension is produced by moving point 1 on the upper plate of the Champlain thrust (CT, cross section 2) eastward so that it 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 arc-complex (OZ). Note the scale change between cross sections 5 and 6. This palinspastic reconstruction provides a relatively accurate method for visualizing the evolution of a mountain belt. It begins with what is known and progresses backward in time to stages where our knowledge of events and structural relations is less certain. Each step of the way is guided by exisiting 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 or Early Middle Ordovician when compression between the North American and Bronson Hill plates had developed an ancient 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 1000 km. This value is reasonable if one considers the terminal velocity of plate subduction to be 60 km/my to 90 km/my (Forsyth and Uyeda, 1975, p. 178). According to Pfiffner 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 latitude of Taiwan, 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 Taconian orogeny. Therefore, we use a figure of 15 million years for the Taconic orogeny beginning just before the emplacement of the allochthons and ending with the final displacement of the sialic slices. Thus, the total shortening would be 1050 km using Taiwan rates (70 km/my, Seno, 1977) which basically agrees with the displacements arrived at by the retrodeformational process.

Construction and significant features of palinspastic cross sections 1-8

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

1. Reversing the deformation from cross sections 1 through 8 requires 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 appropriate slices dictated by the scheme of emplacement. For example, restoring the material eroded from cross section 4 as it evolved to cross section 3 requires that part of Group 2 slices (horizontal lines) appears on top of Group 3 slices (horizontal lines with stipples) in cross section 4. Evidence for this structural sequence, however, is not present today because of extensive post-Taconian erosion. This example simply emphasises 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 (retrodeformation) analysis.

2. The topographic profiles that are assigned for the "Taconian Mountains" during their evolution are realistic if we consider topographic profiles for active converging margins. For example, 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 where the climate was comparable to Taiwan in the Middle Ordovician (Bambach and others, 1980, fig. 6). Thus, the cross sections are dynamic in the sense that they attempt to show not 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). Mass wasting from the upper plate 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 Ordovician wildflysch along the leading edge of and beneath the Giddings Brook slice. Elsewhere, they would disappear as the higher basins were uplifted and eroded to produce more mature deposits. Continual recycling of olistostromal material may well explain the lack of ultramafic debris in the Austin Glen Member of the Normanskill along the front of the Giddings Brook slice. The restored cross sections certainly emphasize the possibility that the material in the Austin Glen could have been recycled many times from its original source and, hence, have nothing to do with the slices 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 becomes apparent as deformation is reversed along eastward-dipping thrust zones in the younger cross sections. For example, in preparing cross section 5, the upper plate of the Middlefield-Hoosac Summit thrust zone (HST-MFZ) in section 4 is moved eastward. This displacement results in the eastern part of the section ending up far below sea level. To correct for this error, the dip of the thrust zone is reduced 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 collision between 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) formed along the steepened fronts. This process was particularly active along the leading edge of the Giddings Brook thrust (GBT) and lead to a complex history of repeated imbrication and tectonic mixing 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 gradually incorporated more and more of the slope-rise section as the North American crust moved eastward into the subduction zone. During this time slices and fragments of oceanic crust 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 with the Taconic slices to produce the relations 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 reported 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 Sutter and others (1984) who suggest that three metamorphic domains can be recognized in western New England: 1) an older high- to medium-high-pressure/low-temperature metamorphism (M1, pl. 2); and 2) two Barrovian sequences - a western low-gradient metamorphism (M2-L.G., pl. 2) and an eastern high-gradient 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 8 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 rests tectonically on lower pressure and lower temperature rocks as ,for example, along the Underhill thrust in Vermont. A younger low-gradient Barrovian metamorphism (M2-L.G.) extended farther to the west (cross section 6, for example) and overprinted the older metamorphic event. The high-gradient metamorphism developed with the emplacement of Group 3 slices (horizontal lines with stipples) and culminated with the westward transport of the sialic slices. The position of the metamorphic isograds on the upper plates of the cross sections after peak meatmorphism is then controlled by subsequent erosion and the relative movement of the respective slices.

9. In cross sections 3-7, the black shales of the Middle Ordovician are shown in as many as four separate basins. Two of these, one between the accretionary wedge and the volcanic arc and the other between the continent and the wedge, persist through all the diagrams. Others are more temporal and are caused by irregularities in 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 and 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 shales of the Walloomsac, Normanskill, Hawley 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 serpentnite 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 graptolite zone 11 time) prior to 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 Early Ordovician if not in the Late Cambrian. The Moretown Formation is here interpreted as a forearc basin deposit receiving material from the eastern volcanic arcs and the emerged parts of the western accretionary wedge producing such debris flows as the Umbrella Hill Conglomerate.

Prior to the time depicted in cross section 8, coarse clastic rocks (CZc) accumulated in active, Late Precambrian, fault-bound basins to the west while seaward albite-rich clastics rocks of the Hoosac and equivalent formations were deposited in similar, but possibly wider basins. These rocks were covered by carbonate rocks and quartz-rich clastic rocks of the carbonate platform which, in turn, grade eastward into deep-water shales, siltstones, and sandstones 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 (cross section 7). At this time, the more highly deformed and metamorphosed high- to medium-high-pressure / low temperature (M1) rocks of the older accretionary wedge moved westward during early displacement on the Whitcomb Summit thrust (WST) and overlapped the eastern part of the Giddings Brook slice. To the east, the younger part of the accretionary wedge, largely made up of tectonized Rowe (RTZ), emerged to form a non-volcanic arc with slide deposits mixing with sediment in the surrounding basins. Middle Orodvician shales are shown in three separate marine basins: one in the eastern forearc region; the second between the non-volcanic arc (RTZ) and the emerged Taconic slices; and the third in an exogeosyncline or back-arc basin to the west of the Taconic slices. Consequently, two non-volcanic arcs developed as the accretionary wedge expanded and encorporated 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 Hazens Notch slices because these slices were probably active at this time.

With continued compression, the deeper and more eastern parts of the slope-rise terrane failed (dashed faults, cross section 7) and overrode the westerly part of the Taconic slice to produce the configuration of cross section 6. Underthrusting of the platform sequence during failure deformed the carbonate platform and slivers of the carbonate platform (OCp) were ripped up and preserved along these younger faults (group 2 slices). This process contined during westward movement of the Taconic slices (cross sections 6 and 5). Secondary accretion was active during all these stages as the Taconic slices moved onto the continent. To the east, the emerged part of the older 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 thicken by the Taconic slices. This thermal event overprinted the older higher pressure subduction-zone event and strain softened the eastern margin so that subsequent deformation folded 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 stipples, cross section 5). With them were carried the basal parts of Group 2 slices (horizontal lines). Fragments of the carbonate platform were undoubtedly incorporated along Group 3 thrust faults at this time. Syntectonic Barrovian metamorphism (M2-H.G.) accompanied 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 5 as the western continuation of the volcanic-bearing allochthonous Hoosac, whose basal thrust (MZF-HST) now forms the eastern border of the Berkshire massif. Again, we believe that basal thrust faults (PHT, HNT, WST) of the Eastern Vermont slices were active. As seen in cross sections 7 through 4, the Hazens Notch, Pinney Hollow and Underhill slices were gradually overridden 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 Rowe thrust zone (RTZ) 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 subsialic 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 to the east were probably the main factors stopping the collision process (Chapple, 1973). The emplacement of the Green Mountain and Housatonic slices produced the Green Mountain anticlinorium and its western counterpart, the Middlebury synclinorium as such basal thrust faults asas the Champlain thrust stepped up over large risers (cross section 2). Subsequent uplift, erosion, deposition of Silurian and Devonian rocks, Acadian deformation and metamorphism, and Mesozoic rifting, all resulted in the configuration of cross section 1. The degree to which Alleghenian deformation contributed to this cross cross section is unknown, although it is presently considered to be very minor.

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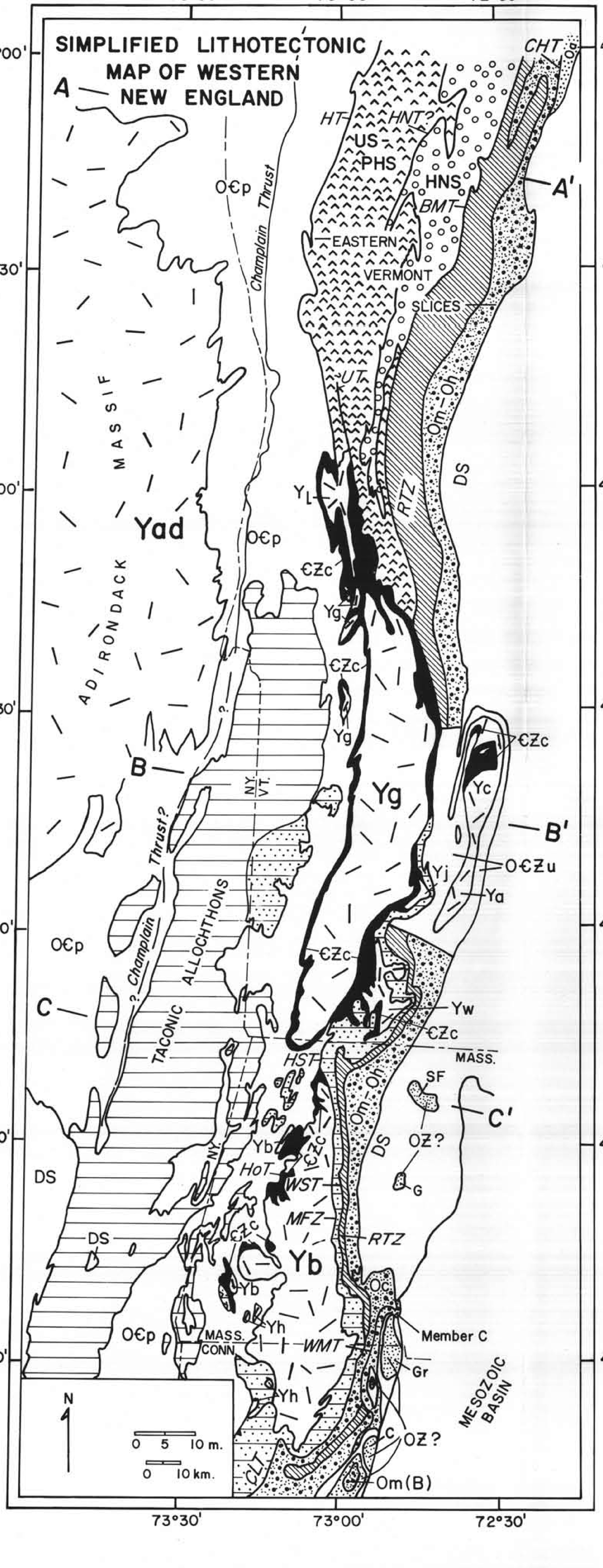

Figure 1

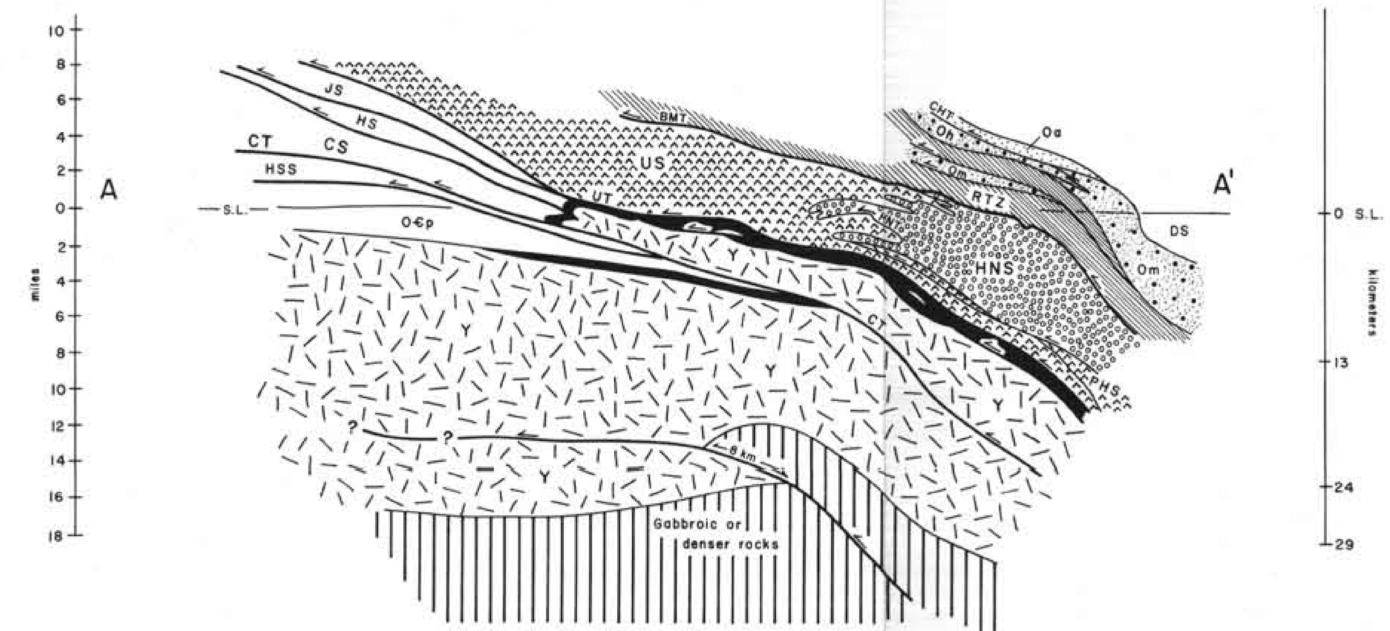

Figure 2

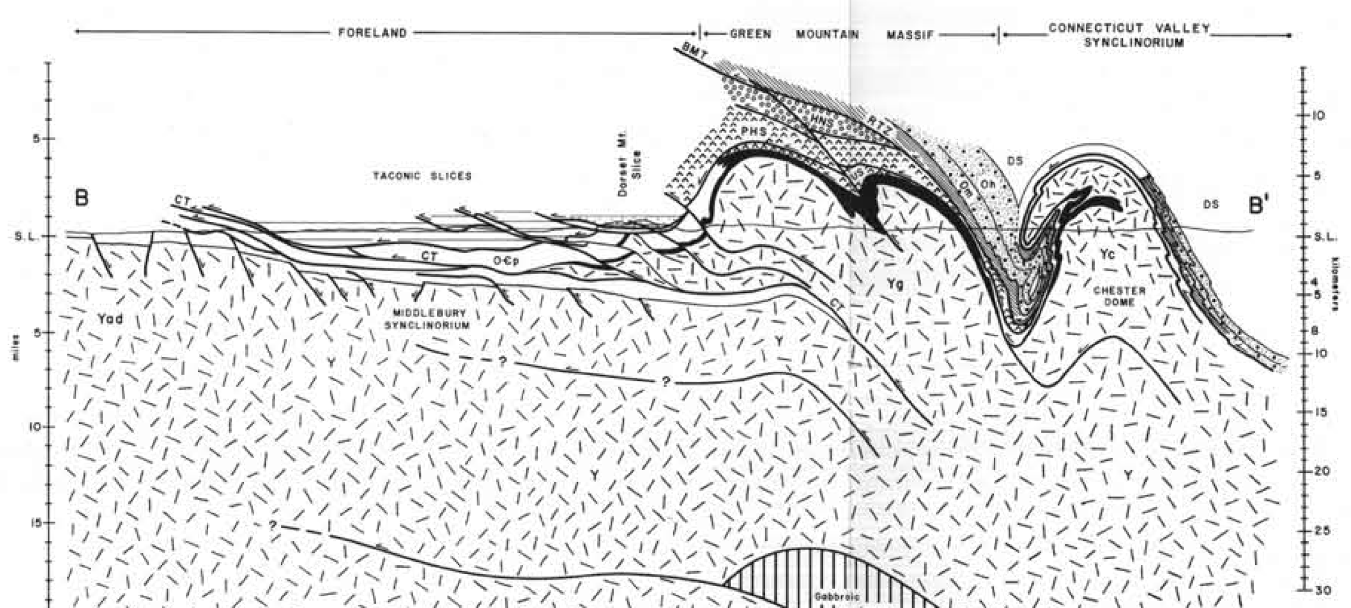

Figure 3

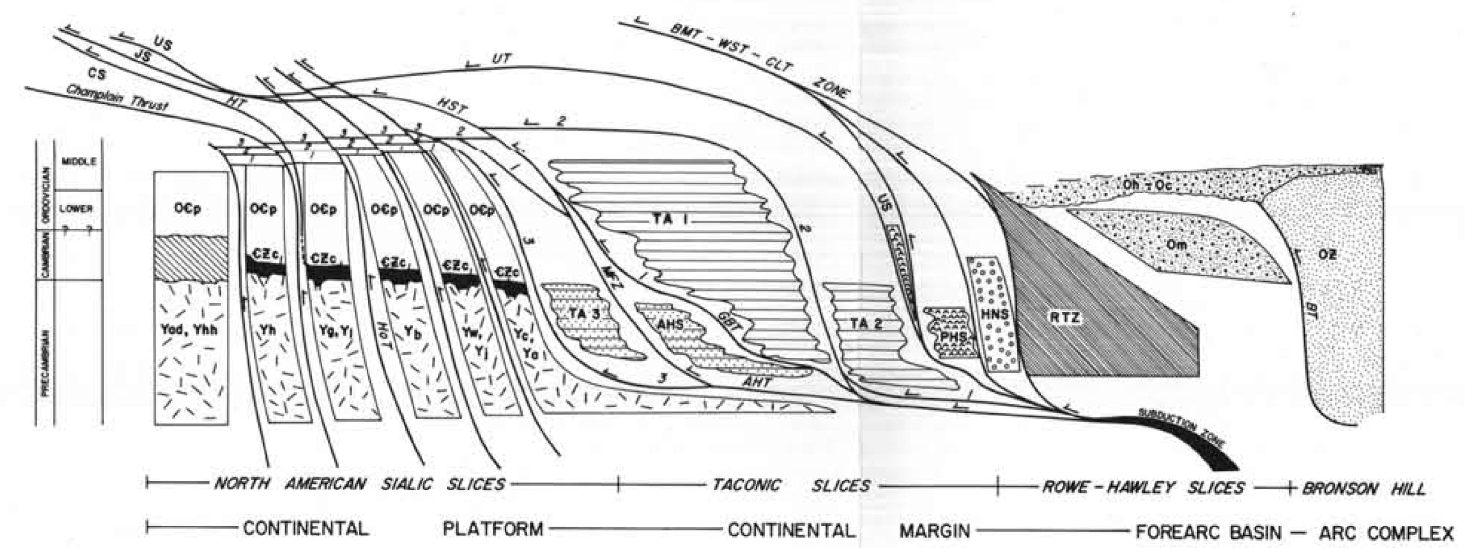

Figure 4

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

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PLATE 1

FIGURE 1

Simplified lithotectonic map of western New England north of latitude 41°40'. Symbols for major structures along the western boundary of each lithotectonic unit are listed between the appropriate units. Descriptions proceed from west to east.

Parautochthonous North American Crust and Cover - Yad, Middle Precambrian of the Adirondack massif; Yg, Middle Precambrian of the Green Mountain massif; Yl, Middle Precambrian of the Lincoln massif; Yh, Middle Precambrian of the Housatonic massif; Y, Middle Precambrian between the Green Mountain massif and the Taconic slices in Vermont; CZc, basal pre-Olenellus rift-clastic rocks (black pattern); OCp, Cambrian-Ordovician rocks of the carbonate-siliciclastic platform (blank pattern).

Taconic Allochthons - Group 1 and 2 slices include: the Livingston slice (Austin Glen) of Fisher (1977), the Giddings Brook slice, the Sunset Lake slice, the Bird Mountain slice, the Berlin slice, the Rensselaer Plateau slice, the Chatham slice, and the Everett slice. These are shown by the horizontal line pattern. Group 3 slices include the Dorset Mountain slice, the Greylock slice, the June Mountain slice and the Canaan Mountain slice. These are shown by the horizontal line pattern with stipples west of Yg and Yb.

BOUNDARY - HoT, Hoosic Thrust.

Allochthonous Berkshire Massif and Proterozoic Y Domes of Southeastern Vermont - Yb, Middle Precambrian of the Berkshire massif; Yw, Middle Precambrian around Wilmington, southeastern Vermont; Ya, Middle Precambrian of the Athens domes; Yc, Middle Precambrian of the Chester dome; Yj, Middle Precambrian at Jamaica; CZc, basal clastic sequence (black pattern) deposited unconformably on Middle Precambrian basement.

BOUNDARY - MFZ, Middlefield Thrust Zone; HST, Hoosac Summit Thrust.

Allochthonous Hoosac Formation - horizontal lines and stipples east of Yb and Yg.

BOUNDARY - CLT, Cameron's Line Thrust; WST, Whitcomb Summit Thrust; UT, Underhill Thrust; HT, Hinesburg Thrust.

Eastern Vermont Slices - OCZu, undifferentiated Cambrian and Ordovician rocks around the Chester and Athens domes; Om, Moretown Formation; Oh, Hawley Formation and its equivalents in Vermont; Oc, Cobble Mountain Formation; Occ, Member C of the Cobble Mountain Formation; US, Underhill slice (includes Pinney Hollow slice - PHS); HNS, Hazens Notch slice; HNT?, Hazens Notch thrust (questioned); RTZ, Rowe thrust zone; BMT, Belvidere Mountain thrust; WMT, Winchell Mountain thrust.

BOUNDARY - BT, Bristol Thrust (not shown); CHT, Coburn Hill Thrust.

Core Rocks of Domes of Western Massachusetts and Western Connecticut - OZ?, Gneisses and amphibolites of the Collinsville Formation in the Shelburne Falls (SF), Goshen (G), Granville (Gr), Collinsville (C), and Bristol (B) domes.

UNCONFORMITY - DS, Silurian and Devonian rocks.

UNCONFORMITY - M, Mesozoic Border Faults.

FIGURE 2

Geological Cross Section A-A' - Cross section modified from cross section A-A' of the Geologic Map of Vermont (Doll and others, 1961). Important relations are: 1. In the allochthonous Eastern Vermont Slices, the Coburn Hill thrust (CHT) places the southern part of the Ascot-Weedon arc complex over the westerly-situated rocks of the Cram Hill and Moretown Formations (Gale, 1980; Hoar, 1981; Doolan and others, 1982); 2. The ultramafic-bearing rocks between the Coburn Hill thrust (CHT) and the Belvidere Mountain thrust (BMT) are cut by numerous thrust faults of possible Taconian age (Stanley and others, 1984). 3. The Hazens Notch slice is folded into a large east-facing structure (Thompson, 1974) and is shown being cut by the Belvidere Mountain thrust (BMT). This suggests that movement on the Belvidere Mountain thrust outlasted displacement on the Hazens Notch thrust; 4. The western part of the Underhill-Pinney Hollow slice of figure 1 consists of the Jerusalem slice (JS) and the Hinesburg slice (HS) based on recent mapping by Tauvers (1982), DiPietro (1983), and Dorsey and others (1983). The Hinesburg thrust roots in the overturned, western limb of Middle Precambrian basement whereas the Jerusalem thrust joins the Underhill thrust along the eastern limb; 5. Displacement on the Champlain thrust is shown to be approximately 25 km. This value is conservative compared to 50 km to 80 km estimates based on seismic interpretation (Ando and others ,1983) and plate tectonic deductions (Rowley, 1982); 6. The regional gravity high beneath the Green Mountain massif is explained as a anticlinal bulge over a deep ramp along a thrust fault. Symbols are explained in figure 1. Heavy lines with arrows are faults. Arrow indicates the displacement of the hanging wall or upper plate. Lighter lines represent depositional contacts.

FIGURE 3

Geological Cross Section B-B' - Cross section modified from cross section E-E' of the Geologic Map of Vermont (Doll and others, 1961). The recent COCORP seismic line (Ando and others, 1983, fig. 3), located directly north of this section, shows the following important features; 1) prominent east-dipping seismic reflections are present throughout the section. These reflections are interpreted as faults; 2) a prominent reflection, which may correspond to the Champlain thrust, is located approximately 4 km (2.5 mi., 13,000 ft.) beneath the topographic surface of the Green Mountain anticlinorium; 3) the top of the sialic crust below the Taconic slices is located at a depth of approximately 4.5 km (2.8 mi., 15,000 ft.), which exceeds by 4000 to 5000 feet the combined thickness of the platform and Taconic sequences. For example, section E-E' (Doll and others, 1961) shows the top of the sialic crust to be at 10,000 to 11,000 feet below sea level. Both cross sections show the base of the Taconic slices at a depth of approximately 5000 feet. We suggest that the apparent increase in thickness of the platform sequence beneath the Taconic slices is due to the presence of the Champlain and associated thrust faults which tectonically thicken the sequence. About 45 km of displacement for the Champlain-Orwell thrust zone is shown in cross section B-B' because the thrust zone must be extended west while maintaining the same depth beneath the Green Mountains that is shown in cross sections A-A' and C-C'; 4) The reflections beneath the Chester dome are interpreted as planar, east-dipping thrusts by Ando and others (1983). This interpretation is too simple because our analysis indicates that these thrusts formed during the latter part of the Taconian orogeny and, therefore, should be folded like the basal Silurian-Devonian contact over the Chester dome. Cross section B-B' also shows that 1) the Belvidere Mountain thrust (BMT) structurally overlaps the Hazens Notch, Pinney Hollow and Underhill slices. This configuration is based on the map relations shown in figure 1; 2) a small thrust slice of Precambrian Y rocks, covered unconformably by the Middle Ordovician Normanskill Shale (Walloomsac, Ira), is present beneath the Dorset Mountain slice. This basement thrust is interpreted to be a reactivated older normal fault along which the upper plate has moved over a ramp to produce the anticline shown in the section. Some of these late Taconian faults are shown cutting the older slices of the Taconic allochthons. This interpretation may explain the presence of other Precambrian blocks between the Green Mountain massif and the Taconic allochthons (see Doll and others, 1961); 3) our analysis indicates that the eastern surface exposure of the root zone for the Taconic slices is located along the east side of the Chester-Athens domes at this latitude. Symbols are explained in figure 1. Heavy lines with arrows are faults. Arrow indicates the displacement of the hanging wall or upper plate. Lighter lines represent depositional contacts.

FIGURE 4

Composite palinspastic diagram for western New England showing relative depositional sites for Late Precambrian to Middle Ordovician rocks deposited on or between the North American continent and the Bronson Hill Arc Complex. Autochthonous carbonate-siliciclastic-shale sequence (OCp) with its clastic rift basal section (CZc) rest on imbricated slices of North American crust (Yh, Yg, Yl, Yb, Yw, Yj, Yc, Ya). To the east along the continental margin are the rocks of the Taconic slices (TA 1, TA 2, TA 3). The irregular edges of TA3, AHS, TA1, and TA2, attempt to portray the gradational stratigraphy among these slices. The Underhill (US), Pinney Hollow (PHS), Hazens Notch (HNS), and Rowe (RTZ) slices represent eastward or basal sequences deposited on transitional or ocean crust. Serpentinized ultramafic rocks occur as slivers along faults in HNS and RTZ. These rocks were deformed repeatedly in the earlier accretionary history of the margin before they were displaced as a whole to the west during the ejection of the Taconic slices. The Bristol thrust (BT), which places the arc-complex of the Bronson Hill (OZ) over the forearc sequence of the Moretown (Om), is unconformably overlain by the Hawley Formation and its equivalents (Oh-Oc). Schematic thrust zones are represented by curved lines with arrows marking the direction of movement. Their relative age is shown by crosscutting relations. For example, the Belvidere Mountain-Whitcomb Summit-Cameron's Line thrust zone (BMT-WST-CLT) is a reactivated zone which has continued to move late in the Taconian orogeny, structurally overlapping and burying beneath it more westerly-situated slices. Thus, it is shown cutting the Hazens Notch (HNS) and Pinney Hollow (PHS) slices. In the Taconic slices the thrust zones flooring the three groups are numbered 1, 2, and 3. The cross cutting relations in their depositional site show when they formed. Group 2 thrust faults, therefore, are shown cutting Group 1 thrusts (GBT). In turn, group 3 thrust faults and their associated branching faults (AHT, MFZ, HST) cut basal thrust faults of groups 1 and 2. The resulting stacking order of Groups 1, 2, and 3, in ascending order and age, are shown to the west on the autochthonous rocks of the continental platform. The thrust faults flooring the sialic slices, which formed late in the sequence, are shown cutting all the easterly derived slices (CT, HT, HoT, and other unnamed faults). Except for the eastern slices of the Taconic allochthons, much of the surface evidence for these age relations has been eroded and is based on our interpretation of the chronology. The slice relations in northwestern Vermont are in the upper-left part of the diagram. The Hinesburg thrust (HT) is shown to die out in the basal part of the Cheshire Formation on the west side of the Lincoln massif (Yg,Yl). Inferred depositional environments and plate tectonic settings are shown at the bottom of the diagram. All symbols correspond to those used in figure 1. AHS refers to the allochthonous Hoosac Formation on the east side of the Berkshire and Green Mountain massifs (fig. 1).

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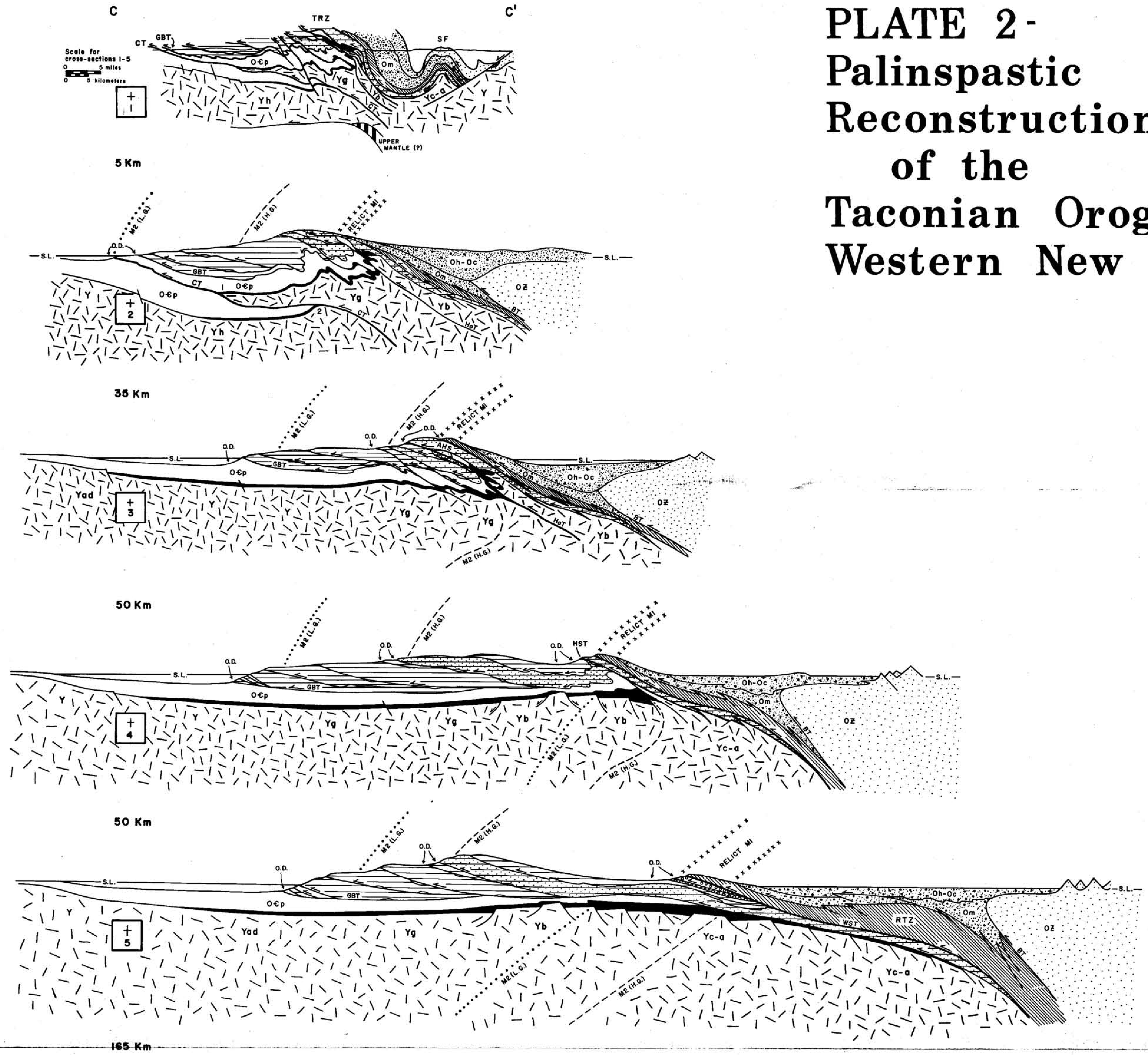
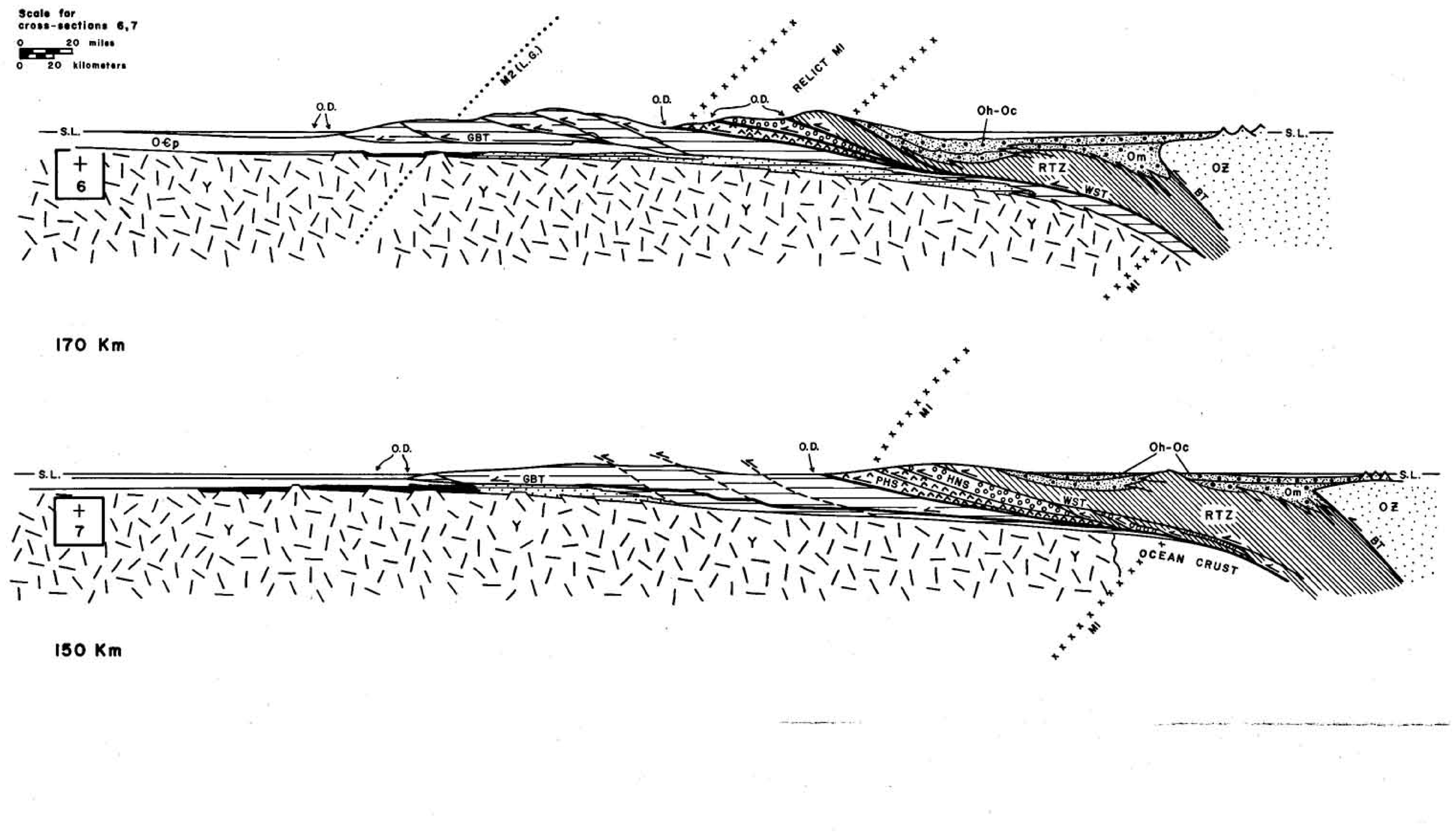
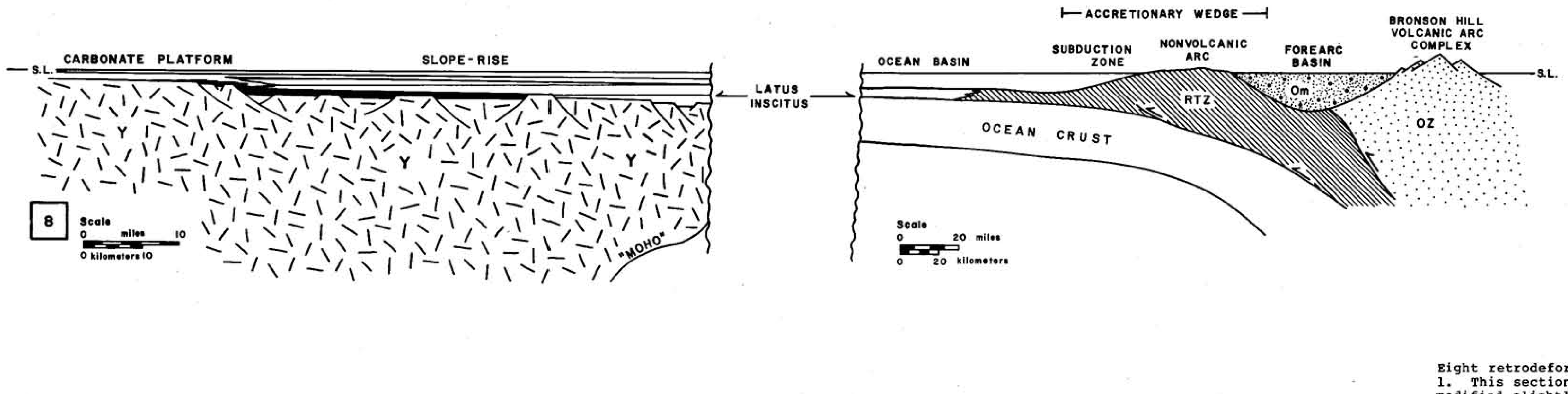
PLATE 2- Palinspastic Reconstruction of the Taconian Orogeny in Western New England







EXPLANATION

- Bronson Hill volcanic arc complex
- Forearc Basin Deposits:
  - Holly-Cobble Mt. Fms and equivalents (Oh-Oc)
  - Moretown Fm (Om)
- Rowe Thrust Zone (RTZ)
- Hazen's Notch Slice (HNS)
- Underhill Slice (US), Pinney Hollow Slice (PHS)
- Taconic Slices (Groups 1, 2)
- Taconic Slices (Group 3), Allocthonous Hoosac Slice (AHS) east of Yb & Yg
- Cambrian-Ordovician Carbonate-siliciclastic Platform (O€P)
- Late Precambrian rift clastic rocks and eastern facies equivalents
- North American Crust:
  - Y undifferentiated
  - Yad Adirondack Massif
  - Yb Berkshire Massif
  - Yc-a Chester and Athens domes
  - Yg Green Mt. Massif
  - Yh Housatonic Massif
  - Yw Wilmington domes

TRZ Taconic Root Zone

CT Champlain Thrust

SF Shelburne Falls dome

M2 Metamorphic isograd

O.D. Olistostromal deposits

150 Km Displacement between adjacent diagrams

+ 3 Reference point with diagram number

—S.L.— Back-arc basin showing sea level

Active thrust fault with platform sliver

Inactive thrust fault with platform sliver

Eight retrodeformed cross sections beginning with cross section C-C' of figure 1. This section extends from central Massachusetts to Albany, New York, and is modified slightly from section A-A' of Ratcliffe and Stanley, in Zen and others (1983) so that the fault-riser in the lower thrust deforms the higher sialic slices of the Housatonic and Green Mountain massifs into broad anticlines. The Champlain thrust is shown cutting the surface along the western side of the Giddings Brook slice. Symbols are explained in figure 1. Heavy lines with arrows are faults. Arrow indicates the displacement of the hanging wall or upper plate. Lighter lines represent depositional contacts. The calculated displacement between each diagram is shown to the left and represents the the extension of the cross section generated by going from the lower-numbered cross section to the higher. For examples the extension of the cross section from diagram 2 to 3 is 35 km which is the estimate of displacement needed to return point 1 to point 2 along the Champlain thrust fault. Using this method each of the sections are retrodeformed according to the chronological development of major structures of the Taconian orogeny.

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