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TECTONIC SETTING AND MECHANISM OF THE TACONIC SLIDE*

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ABSTRACT. The Taconic klippe in the northern part of the Appalachian Mountain belt is at the western margin of the Appalachian orthogeosyncline. The klippe, which is an extensive feature of the Taconic Range and vicinity, includes eugeosynclinal Cambrian and Lower and Middle Ordovician rocks and overlies miogeosynclinal rocks of the same age span. Lithically and sequentially similar eugeosynclinal rocks east of the klippe are autochthonous in the interior of the orthogeosyncline. The klippe probably was detached by gravity sliding from an eastern terrane later eroded, as the slide surface beneath the klippe has only limited roots in the autochthon. Wildflysch in the subjacent autochthon indicates sliding during Middle Ordovician. The klippe, containing 4500+ feet (1400 m) of eugeosynclinal rocks, slid westward from a geanticline (now the site of a gravity high) into a trough containing 7000+ feet (2000+ m) of miogeosynclinal rocks. It is proposed that abundant fluids were expelled, during compaction and regional metamorphism, from eugeosynclinal rocks that are more than 20,000 feet (7000 m) thick on the opposite (east) side of the geanticline, and that the fluids migrated westward into the thinner eugeosynclinal rocks on the geanticline. Sufficient fluids arrived, despite expectable leakage on the way, to compensate for leakage from the geanticlinal rocks during the Cambrian to Middle Ordovician episodes of sedimentation. Relief on the geanticline was least compensated by sedimentation on the west flank. When this relief became sufficient during Middle Ordovician, enough fluid pore pressure had been maintained down to the level of the Lower Cambrian to float the klippe westward. Sliding possibly took place in a similar way at other places in the Appalachian-Caledonian and also the Alpine regions as suggested by their partly comparable tectonic relations.

INTRODUCTION

The Taconic Range and vicinity in western New England and eastern New York contain some of the best known and largest klippen in the Appalachian Mountain belt (fig. 1). The terms "Taconic klippe" and "Taconic slide" refer in general to several variously interpreted and more or less contiguous klippen and the slides beneath them (Zen, 1967, p. 12-28), but for simplicity the northernmost, which is eroded into two separate parts (Doll and others, 1961, sec. *C-C′*), is here used to illustrate sliding (fig. 2).

The word "Taconic", now commonly associated with a diastrophic episode in the later Ordovician, has signified various things, many controversial, over the past century and a quarter. In 1842, Ebenezer Emmons (p. 149, 163) concluded that the lower rocks of the Taconic region were beneath the Potsdam Sandstone and in the "Primordial" or Lower Cambrian. This conclusion was later supported by paleontologic evidence and by arguments, provided by Joaquim Barrande in 1861 and by S. W. Ford in 1871. Emmons was opposed in this by James Hall (1847, p. 31), who contended that the Taconic rocks were Middle Ordovician or younger (see also Billings, 1862). As it has turned out, the rocks of the region range through the whole of the Cambrian and the Lower and Middle Ordovician, and the dilemma of abnormal superposition of older on younger rocks was resolved by W. E. Logan in 1861 (p. 381) in a letter

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to Barrande. This letter contains one of the earliest published recognitions of thrust faults anywhere in the world—along "Logan's Line" in Quebec, Vermont, and New York—one of which faults, in 1841, Emmons (1855, p. 87-89; 1888, p. 98-100) had described as a vertical fault upthrown to the east. A klippe was proposed in 1909 by Rudolf Ruedemann (p. 191) and was defined by Arthur Keith in 1913.

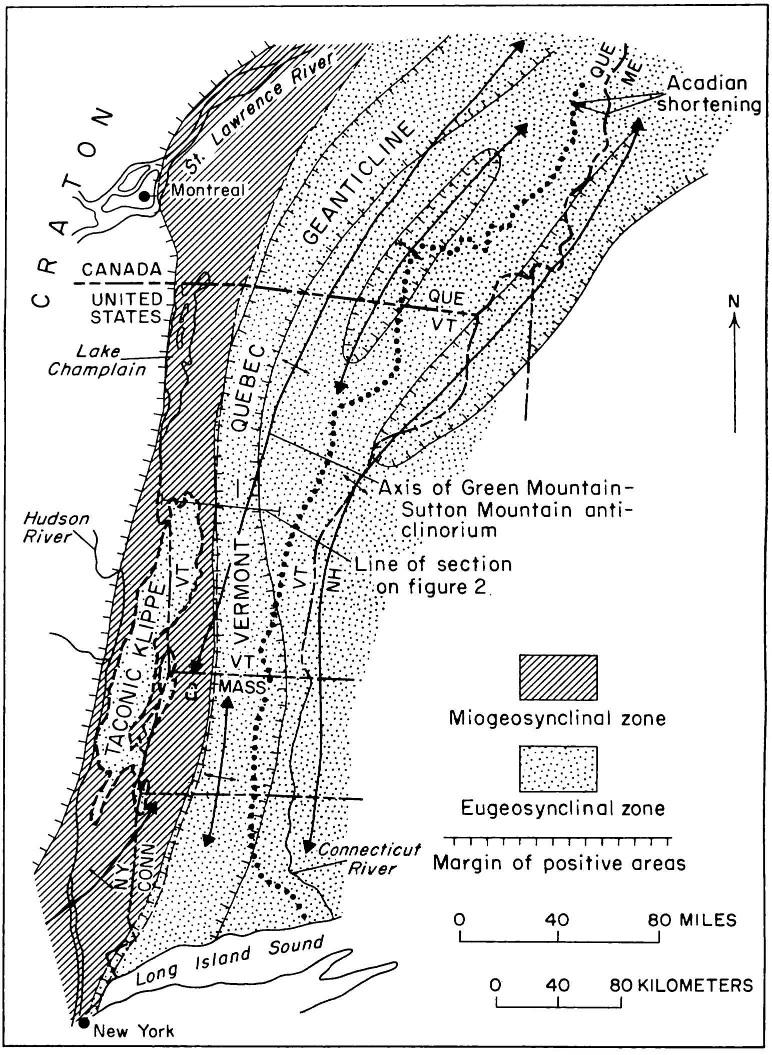

Fig. 1. Paleotectonic map of the Middle Ordovician of western New England, eastern New York, and adjacent Quebec drawn on a palinspastic base to remove distortions of geosynclinal features produced by Devonian Acadian folding and thrusting —dotted line shows present positions of the Connecticut River and the international boundary between Quebec, and New Hampshire and Maine.

A very recent controversy has concerned the extent of a Taconic allochthon and indeed its very existence—a controversy outlined in detail by Zen (1967, p. 89-92) and settled by him in favor of the allochthon. The principal current discussions deal with: (1) the extent to which the source terranes of the Taconic klippen and the root zones of the Taconic slides are preserved and may be identified (Zen, 1967, p. 56-62); (2) the abundance of parautochthonous thrusts that root in the autochthon and transect the Taconic slides (Doll and others, 1961; Potter, 1963, fig. 2, p. 61, 64; Thompson, 1959, p. 72-86)—as opposed to multiple slides, beneath several slices of strictly allochthonous rocks (Zen, 1967, p. 12-28), that involve only slivers of the autochthon dragged up by the moving allochthon (Zen, *in* Cady and Zen, 1960, fig. 5; Zen, 1961, pl. 1, 1967, p. 31-34); and (3) the mechanism of movement of the Taconic allochthon on the Taconic slides, to be discussed here.

The current problems of the Taconic rocks and structures are simplified by the fact that the rocks of the klippen are of a type transitional to the eugeosynclinal assemblage, and that the autochthonous rocks beneath and to the west of the klippen are clearly of the miogeosynclinal zone and cratonal cover. Thus the source of the allochthon was a terrane evidently transitional between the miogeosynclinal and eugeosynclinal zones, 10 miles or more east of the eastern edge of the klippen. H. E. Hawkes (1941) showed that the transition, and presumably a root zone, must have involved rocks near those of the present Green Mountain ridge, in west-central Vermont. W. S. White (Cady, 1945, p. 570) suggested that the Taconic slide has no root and that the allochthonous rocks moved westward after detachment from an eastern terrane later eroded. This suggestion implies that the principal mechanism was gravity sliding, an interpretation supported by Thompson (1952, p. 20), Zen (1961, p. 328-329), and the author (Cady, 1945, p. 578-579; also 1967, p. 63-64).

Zen's (1961, p. 311, 328) recent discovery of wildflysch in the Middle Ordovician rocks of the autochthon shows that the allochthon moved westward during the Middle Ordovician, well before the climax of the Taconic disturbance. Zen proposes, following Hubbert and Rubey (1959), that a high ratio of pore fluid pressure to rock pressure may have made movement possible, and Platt (1962, p. 109-110) suggests that fluids derived from igneous rocks may have been responsible.

The Taconic slide is here interpreted from the perspective of a regional tectonic setting that significantly influenced the mechanism.

TECTONIC SETTING

The Taconic klippen are erosional remnants of a slightly more extensive allochthon folded in a foreland synclinorium (Zen, 1961, p. 325; 1964, p. 64; 1967, p. 12-13)—the Middlebury-Hinesburg-St. Albans synclinorium (Cady, 1960, p. 535)—west of the Green Mountain-Sutton Mountain anticlinorium in eastern New York, western New England, and southeastern Quebec (fig. 1). Subsidiary major folds on the east limb of the Green Mountain-Sutton Mountain anticlinorium, a little north of the international boundary in Quebec, involve paleontologically well established Silurian and Devonian strata (Cady, 1945, p. 580; 1960, p. 564). Moreover, Silurian and Lower Devonian strata are included in the east limb of the axial anticline of the anticlinorium in southern Vermont (Doll and others, 1961). Hence the final and also dominant episode of folding, including that of the adjoining Middlebury-Hinesburg-St. Albans synclinorium to the west, was probably during the Devonian Acadian orogeny.[1] The anticlinorium and synclinorium are characterized both by folds that are grossly parallel (concentric) in style and by east-dipping foreland thrust faults (Cady, 1945, p. 577-579, 580; 1960, p. 536, 564). This folding and thrusting involved Precambrian basement as well as Paleozoic rocks and structures, including the Taconic allochthon of Middle Ordovician age (Doll and others, 1961; Thompson, 1959, p. 72).

Restored to its Middle Ordovician condition, after sliding and before Acadian folding and thrusting (fig. 2), the Taconic allochthon overlay a geosynclinal trough on the mobile shelf adjoining the craton. This trough was about in the belt that later became the Middlebury-Hinesburg-St. Albans synclinorium. A major positive tract (see footnote [1]) to

[1] Zen (1967, p. 70-71) suggests that the Middlebury synclinorium started to form in the Middle Ordovician, citing as evidence, (1) flexural folds in lower Middle Ordovician and older strata overlain unconformably by Middle Ordovician and (2) Middle Ordovician high-angle faults, chiefly normal faults appropriately downthrown to the west on the east limb of the synclinorium and to the east—west of the west limb of the synclinorium. However, as Zen's (1964, p. 2) structure sections *B-B′* and *C-C′* show, the unconformity beneath the Middle Ordovician Ira Formation passes up, eastward, and over flexural anticlines (and also flowage folds) at and north of West Rutland and in the Pittsford-Chippenhook belt to the east of West Rutland—truncating successively lower and lower stratigraphic units. The Ira Formation, which participates in the flexural folds, laps eastward onto the eroded lower units—up and down over the flexural folds. Thus the unconformity truncates the west side of a major early positive tract rather than the later formed flexural anticlines, in which it is folded. (There is no evidence that the unconformity is involved in the flowage folds.) These structure sections (Zen, 1964, pl. 2, secs. *B-B′*, *C-C′*) also show the correct relations of the Pine Hill fault, which is a thrust fault transecting the unconformity and the overlying Ira Formation. The sinuous pattern of the Pine Hill fault relative to topographic features (Doll and others, 1961) is alone good evidence that most of the fault is a thrust that dips 45° or less to the east. Two of three high-angle faults mapped in the east limb of the Middlebury synclinorium in Vermont (Doll and others, 1961) are downthrown to the east; that of Thompson (1959, p. 72) north of Dorset Mountain, which is one of the two, is unconformably overlain by the Ira Formation. Potter (1963, p. 61, 64) mapped and described numerous reverse faults on both limbs of the Middlebury synclinorium in east-central New York that show the same east-side-up movement sense as the Pine Hill thrust and cut not only the Middle Ordovician Walloomsac Slate (= Ira Formation) but the structurally superjacent Taconic allochthon. The high-angle faults on and west of the west limb of the Middlebury-Hinesburg-St. Albans synclinorium along the Adirondack front, which Zen (1967, p. 71) suggests form the west side of a graben coincident with the future Middlebury synclinorium, cut flexural folds and the Champlain thrust (Doll and others, 1961; Welby, 1961, pl. 1), and both cut and are cut by dike rocks (Buddington and Whitcomb, 1941, p. 86; Hudson and Cushing, 1931, p. 101) of middle Mesozoic age (Zartman and others, 1967, p. 862, 867); thus they are probably much younger than flexural folds and thrust faults and the high-angle fault north of Dorset Mountain whose age is established by unconformable overlap of the Middle Ordovician Ira Formation. Middle Ordovician high-angle faults west of the west limb of the Middlebury synclinorium in the Saratoga Springs, New York, area are of uncertain origin and may be interpreted as features either of "hard rock" or penecontemporaneous deformation (Fisher and Hanson, 1951, p. 808-809).

the east, the Vermont-Quebec geanticline, is transected at a small angle by, and is not to be confused with, the later-formed Green Mountain-Sutton Mountain anticlinorium (fig. 1). The geosyncline and geanticline are within the northwestern border of the lower and middle Paleozoic orthogeosyncline (Cady, 1967, p. 57-64).

Eugeosynclinal and miogeosynclinal zones.—The orthogeosyncline in the Taconic region includes a broad and thick eugeosynclinal zone, a miogeosynclinal zone to the west on the mobile shelf, and several geanticlines. Both the geosynclinal zones contain variously metamorphosed lower and middle Paleozoic marine bedded rocks that unconformably overlie a miogeosynclinal Precambrian basement complex chiefly of interbedded gneiss, schist, marble, and quartzite (see also Young, 1968, p. 117). The eugeosynclinal rocks are predominantly slate, phyllite, and schist, with which are interbedded discontinuous and relatively thin metaquartzite, granofels, greenstone, amphibolite, and metarhyolite units —metamorphic derivatives of shale and graywacke (collectively semipelites), minor quartz sandstone, and mafic to felsic volcanic rocks. The miogeosynclinal rocks comprise quite continuous interbedded marble, quartzite, and slate units—clearly metamorphic derivatives of limestone, dolomite, quartz sandstone, siltstone, and shale that remain unmetamorphosed near the margin of the craton. Pelitic and semipelitic rocks, especially common in the upper part of the eugeosynclinal zone, overlap both the geanticlines and the cratonal margin. The stratigraphic section in the eugeosynclinal zone is two to at least five times as thick as in the miogeosynclinal zone—the maximum thickness of the Cambrian and Lower and Middle Ordovician rocks in the miogeosynclinal zone is about 10,000 feet (3000 m), whereas the thickest section of rocks of the same age in the eugeosynclinal zone (northeast of the Taconic region) is probably at least 50,000 feet (15,000 m).

The miogeosynclinal and eugeosynclinal zones coalesce laterally (Cady, 1960, p. 557), and the transition is marked by a change in sedimentary facies and total thickness of the rocks. Where geanticlines intervene between the zones, the stratigraphic sections thin out. The thinning is by unconformity and stratigraphic convergence toward the transition zone. The transition zone is eroded from the southern Vermont and western Massachusetts and Connecticut areas, and the Precambrian basement is exposed east of the Taconic klippe; but northeast of the klippe, where at least Cambrian rocks are preserved, the transition zone can be traced into the Champlain and St. Lawrence Valleys (fig. 1).

Plutonic igneous rocks, with the exception of ultramafites, are emplaced only in the southeastern part of the eugeosynclinal zone. The ultramafites and commonly associated mafic volcanic rocks extend almost to the western edge of the autochthonous eugeosynclinal zone, but only the mafic rocks are found in the transitional eugeosynclinal terrane of the Taconic klippe.

Geanticlines.—The geanticlines (fig. 1), long structural highs including tectonic islands, paralleled the trend of the orthogeosyncline in the

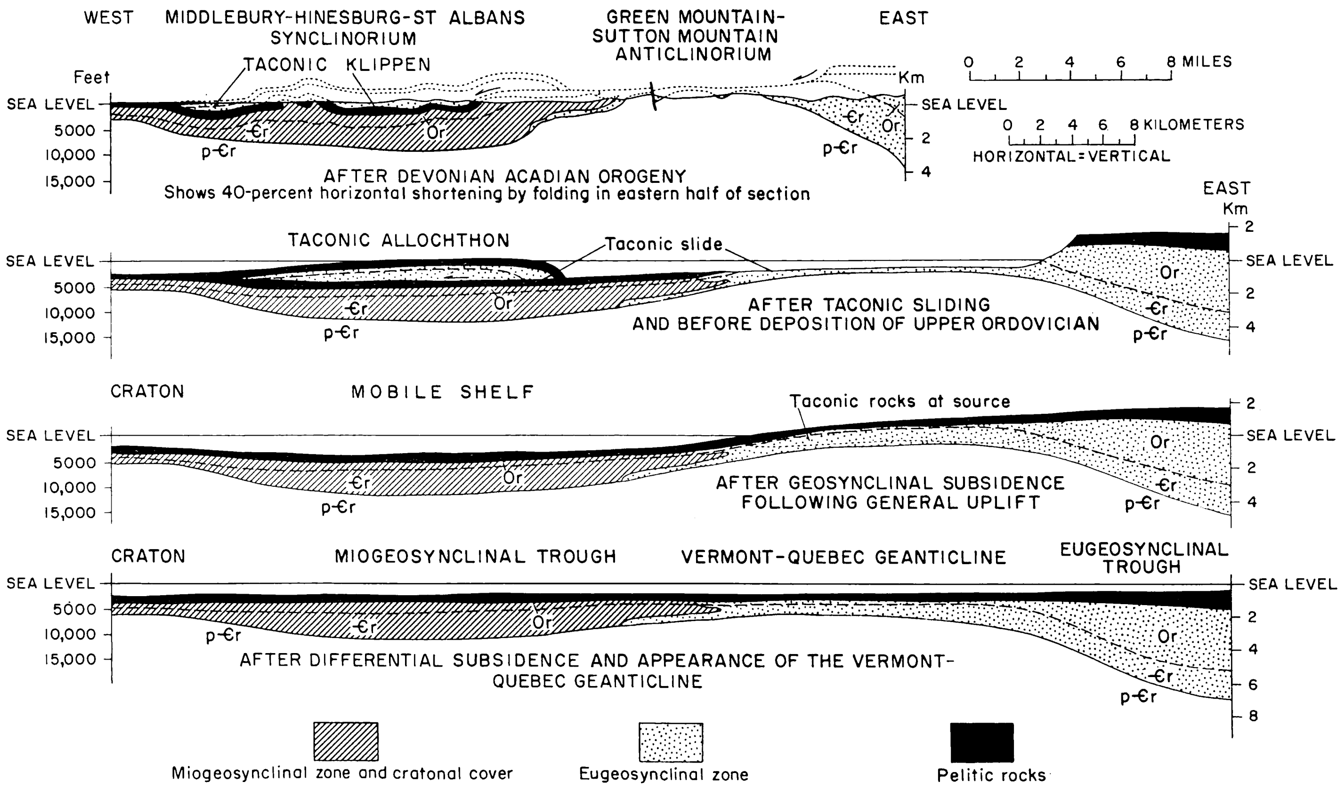

Fig. 2. Restored sections of the Middle Ordovician and older rocks of the northern Taconic region, before and after sliding of the Taconic allochthon; line of sections shown on figure 1. Or, Ordovician rocks; Cr, Cambrian rocks; pCr, Precambrian rocks.

early and middle Paleozoic. Unconformable overlap and stratigraphic convergence toward their axes show their former existence. They were relatively stable tracts of slowed deposition or nondeposition during subsidence of adjacent geosynclinal troughs and of local erosion during episodic general uplifts of the orthogeosynclinal belt, and they were terranes of relatively mild deformation during later orogenic folding.

Two of the three known geanticlines coincide with present gravity highs (Am. Geophys. Union and U. S. Geol. Survey, 1964; Cady, 1967, p. 62, 63, 65), at least one of which highs was possibly caused by warping and/or faulting of density discontinuities in or at the base of the Earth's crust (Diment, 1956). This possibility suggests that dense crustal layers were left structurally high when adjoining geosynclinal troughs subsided. If the geosynclinal subsidence is an expression of crustal subsidence shown by gravity data, those data must reflect uncompensated anomalies that have persisted since the geanticlines first formed in early Paleozoic time—showing continued crustal strength from that time to the present (see also Innes and Argun-Weston, 1967, p. 74-76; Zen, 1967, p. 73).

Whatever its basic cause, quasi-cratonic crustal strength evident in the vicinity of the geanticlines is to a degree comparable to that of the craton nearby to the west and is consistent with the miogeosynclinal affinities of the underlying Precambrian basement from which some stability is probably inherited. It suggests that the crustal mobility required to direct westward movement of the Taconic allochthon originated east of the geanticlines. Uplift inferred at least 50 miles (80 km) east of the Vermont-Quebec geanticline (Cady, 1967, p. 59), possibly caused by lateral compression of more mobile eastern crust, was translated into subhorizontal westward gravity flow of the rocks until they filled the geosynclinal trough east of the geanticline, and sediments, also from the east, surmounted the geanticline.

The Vermont-Quebec geanticline is westernmost and is probably the source of the Taconic allochthon. It coincides with the axis of the Acadian Green Mountain-Sutton Mountain anticlinorium in west-central Vermont and to the northeast in Quebec, but it is west of this axis in northern Vermont and nearby parts of Quebec and east of it in southern Vermont. Its western flank also coincides closely with the belt of transition between miogeosynclinal and eugeosynclinal zones in New England and neighboring Quebec, but farther north its northeastward trend, shown by intermittent lateral occurrence of quartz sandstone, dolomite, and limestone, puts it well within the eugeosynclinal zone. The northeastern extension of the geanticline is perhaps the source of enormous blocks in the limestone conglomerate and associated shallow-water clastic sediments that were spilled from the southeast into the northwestern part of the eugeosynclinal zone in Quebec (Osborne, 1956, p. 197-198).

The eugeosynclinal rocks on the Vermont-Quebec geanticline in northern Vermont and adjacent Quebec, though thicker, are lithically and sequentially most like those in the Taconic klippen. Therefore rocks of the klippen are inferred to have been deposited as sediments atop the geanticline in and south of west-central and southern Vermont, although they are now widely eroded from the southern areas (see also Doll and others, 1963, p. 95; Zen, 1961, p. 333). Moreover, the sections preserved in the klippen are thinner throughout (4500+ ft or 1400± m) than sections of corresponding age either in the eugeosynclinal zone east of the geanticline (20,000+ ft or 7000+ m) or in the autochthonous miogeosynclinal zone (7000± ft or 2000+ m) beneath the klippen (Osberg, 1959, p. 45-46; Theokritoff, 1964; Thompson, 1952, p. 40; Zen, 1961, p. 297, 299, 331-333). This is probably the result of stratigraphic convergence and unconformable overlap toward the geanticline (Cady, 1967, p. 63).

The thinness of the section in the Taconic allochthon, especially of the sand and shale clastics, has also been ascribed to the distance from their eastern source (Zen, 1967, p. 47). Westward and eastward attenuation of, respectively, the eugeosynclinal and miogeosynclinal clastics does not, however, seem to be the sole explanation of the thinning inasmuch as nonclastic carbonate rocks, which predominate in the miogeosynclinal zone west of the original site of the allochthon, also thin (eastward) toward the latter site. Had the geanticline been absent, carbonate rocks would probably have filled parts of the section at the source of the allochthon that were out of reach of the clastic sediments, thus maintaining a thickness at least equal to that of the miogeosynclinal zone. This seems clear because shallow-water carbonate rocks and clean quartz sandstones do actually fill in parts of the existing section in the allochthon (Zen, 1961, p. 303, 304, 306-307; 1964, p. 16-17, 19, 21-22) as well as parts of its autochthonous equivalent exposed downplunge to the north (Clark, 1934, p. 10; 1936, p. 143, 146-149); conversely, dirty sand and shale-clastic rocks like those dominant in the allochthon and in northern autochthonous equivalents occur within the miogeosynclinal section (Osberg, 1959, p. 46; Shaw, 1958, p. 528-529, 536-537, 539-540, 547; Zen, 1961, p. 309-310; 1964, p. 37-44). Thus the differences in water depth between the Taconic and miogeosynclinal settings were neither great nor irreversible, nor such as would alone cause thinning of either clastic or nonclastic sediments toward the Taconic section.

Scarps such as might mark the eastern edge of a carbonate shelf or bank are probable. From such scarps some clastic carbonate material was distributed eastward (Bird and Theokritoff, 1967), and at some stratigraphic levels the scarps mark sharp facies contrasts. However, in northwestern Vermont where their relations are most clear the sharp facies contrasts are at various intermittent stratigraphic levels, separated from each other by typical miogeosynclinal carbonate rocks that extend farther east and thin out where (approaching the geanticline) the sections converge stratigraphically and overlap unconformably eastward (Cady, 1960, p. 538-539; Dennis, 1964, p. 28-31; Stone and Dennis, 1964,

p. 29-35, 40-43). It is therefore probable that scarps of east-facing carbonate shelves or banks of various ages were neither distributed along a common line nor were they features necessarily continuous in time, and that where their record is best preserved they are west of the proposed Vermont-Quebec geanticline.

Tectonic thinning does not appear to have been involved in the relative thinness of the Taconic rocks, inasmuch as some of even the least deformed sections (Theokritoff, 1964) are very thin.

Early folds and slides.—The Taconic slides are members of a family of structural features formed chiefly in the eugeosynclinal zone at various times in the early and middle Paleozoic before the Devonian Acadian orogeny. These features include major recumbent folds commonly similar in style, intrastratal diapiric folds, and syntectonic ultramafites. They were bowed up in domes and arches, flexed in anticlinoria and synclinoria, and intersected by parautochthonous thrust faults at the climax of the Acadian orogeny (Cady, 1967, p. 65-66). The slides and folds face westward, and the ultramafites were tectonically entrained in that direction. The folds are most common in the interior of the orthogeosyncline, whereas the slides are nearer its margin.

The surfaces of the Taconic slides (collectively the *Taconic slide*) are beneath the several slices that comprise the allochthon and that slid from successively eastern (fig. 2), central, and western sites in the root terrane,[2] which was probably on the top and west flank of the Vermont-Quebec geanticline. The slices were each detached at about the same stratigraphic level in lowest Cambrian rocks, marked especially at the western sites of detachment by a relatively greater abundance of sandstone interbedded in the otherwise pelitic rocks (Zen, 1967, p. 18, 49, 52, compare with p. 15, 66-67). The sandstone units from the central (Zen, 1964, p. 11-18, 22; 1967, p. 22-28) and eastern sites (Theokritoff, 1964, p. 178-182; Zen, 1961, p. 299-308) of detachment, and also at upper stratigraphic levels throughout the allochthon, are smaller and discontinuous. The slices from eastern sites, emplaced first and farthest travelled, are transected and overridden by those (not shown in fig. 2) from the sites to the west. The youngest, Middle Ordovician, rocks in the allochthon are preserved in the tectonically lower of the slices that have not yet been reached by erosion.

INTERPRETATION OF MECHANISM

The cross section of the eugeosynclinal zone, miogeosynclinal zone, and the included Vermont-Quebec geanticline restored to the Middle Ordovician (fig. 2) suggests the mechanism of the Taconic slide. The metamorphic rocks, chiefly in the thick eugeosynclinal section east of

[2] The author interprets the various slices comprised in the Taconic allochthon as follows, in the order of their emplacement: (1) the single Giddings Brook-Sunset Lake allochthonous slice, in two klippen—probably two parautochthonous slices; (2) the Bird Mountain and Chatham slices, in several klippen—possibly one allochthonous slice, probably including the upper rocks of the Dorset Mountain-Greylock parautochthonous slice; and (3) the Rensselaer slice. (Compare with Zen, 1967, p. 12-28, 66-67.)

the geanticline, grade and converge stratigraphically westward into the less metamorphosed and relatively thin eugeosynclinal section on the geanticline that in turn grades westward into the least metamorphosed and somewhat thicker miogeosynclinal zone west of the geanticline. It is proposed that the section east of the geanticline provided a continuously voluminous gathering ground from which fluids expelled from the rock successively by compaction (see Maxwell, 1962, p. 295-297) and by regional metamorphism (see Engel and Engel, 1960; White, 1957, p. 1678-1679; 1965, p. 360-362) were able to move westward into the thin section on the geanticline, and despite expectable leakage on the way, to arrive in quantity enough at least to compensate for leakage in the geanticlinal section during the long episode of Early Cambrian to late Middle Ordovician sedimentation. Thus, when in the late Middle Ordovician the relief of the geanticline had become sufficient through nearby geosynclinal subsidence—most effective on the western flank where not fully compensated by accumulated clastic sediments—enough fluid-pore pressure had been maintained down to the Lower Cambrian level to float the Taconic allochthon westward.

Sediments were deposited almost continuously in the eugeosynclinal zone east of the geanticline during the 100 ± m.y. interval from the Early Cambrian through the Middle Ordovician. Their predeformational thickness and width from east to west were as much as 7 km and more than 15 km, respectively (see Doll and others, 1961, sections *C-C′, D-D′*), giving a cross-sectional area of about 100 square km. Possibly 25 square km of the sectional area represented pore water alone (see Maxwell, 1962, p. 297) under lithostatic pressure, confined above by impervious rocks (see also Heard and Rubey, 1966, p. 748-749), and able to escape only to the west as rocks to the east were compacted, deformed, and metamorphosed—progressively westward. The cross-sectional area of the sediments on the geanticline—1.5 km thick and 25 km from east to west—was 35 to 40 square km; the sectional area of the pore water, replenished from the east at least to make up for leakage from the geanticlinal rocks, was possibly 10 square km.

The rocks in the allochthon, though predominantly pelitic, significantly include discontinuous metasandstone units in their deeper parts, near the Taconic slide. Thus rocks of lower permeability pervaded the allochthon and surrounded and thickly overlaid layers above the slide that (before metamorphism) were more permeable than the pelites and likely to absorb fluids. The fluids, chiefly water, were squeezed out of the pelites in response to lithostatic pressure and trapped in the porous sandstones in and east of the root zone of the allochthon, having been unable to rise vertically to the surface through the impermeable pelites, although they were less dense. As a result, anomalously high pore pressures were developed in the sandstones (see also Bredehoeft and Hanshaw, in press; Dickinson, 1953, p. 426-427), especially in the thick geosynclinal section to the east of the root terrane on the Vermont-Quebec geanticline. As the geosynclinal rocks were progressively compacted and metamorphosed, the fluids escaped westward along the permeable sandstone layers into the root terrane, where they maintained the pore pressure necessary to support the weight of the overburden and float the allochthon. The Middle Ordovician rocks at the top of the stratigraphic sections both beneath and resting upon the Taconic slide are part of a continuous and widespread pelitic facies that probably eased movement of the overriding allochthon (Cady, 1945, p. 560, 579), especially where it included uncompacted sediments in an environment of seawater (see Zen, 1961, p. 328; 1967, p. 69).

Simple aquifer head controlled by the downward and lateral seepage of water under the pull of gravity, as opposed to the anomalously high pressures produced by loading and compaction discussed above, probably contributed little to the flotation of the allochthon, because such head could operate only in the most superficial rocks in which vertical rise of water caused by lithostatic pressure is negligible (see Mansur and Dietrich, 1965; Morris and Johnson, 1967, p. D21). Osmotic pressures across shale beds serving as semipermeable membranes (Hanshaw and Zen, 1965; Hubbert and Rubey, 1959, p. 149-156; Zen, 1963, p. 932) seem unlikely because possibly requisite evaporite beds are not known, nor would they be normally expectable in the eugeosynclinal zone. Igneous intrusions are an unlikely cause of anomalously high fluid pressures, because only ultramafites—which as serpentinite derived their water from the adjoining sediments instead of having contributed water to them—are found in the vicinity of the Taconic slide. Extensive deep crustal or subcrustal bodies of serpentinite that might provide water (Raleigh and Paterson, 1965, p. 3983) in amounts comparable to that available in sedimentary and metasedimentary rocks are unlikely (see Hess, 1966, p. 5-6; Thompson and Talwani, 1964, p. 4834).

Formation of the Taconic allochthon by slide mechanics, as opposed to recumbent folding alone without detachment, suggests flotation of the rocks at a fairly discrete slightly inclined surface marking the sharp transition from the dry highly metamorphosed rocks of miogeosynclinal assemblage in the Precambrian basement to the unmetamorphosed fluid-bearing rocks in the Cambrian and Lower and Middle Ordovician eugeosynclinal section on the Vermont-Quebec geanticline. This interpretation is supported in a negative way by the predominance of undetached recumbent folds to the east, in the much thicker Paleozoic rocks of the interior of the eugeosynclinal zone. There, load metamorphism, possibly assisted by tectonic overpressure, provided a more gradual upward transition from the Precambrian basement. (See also Heard and Rubey, 1966, p. 754-755; Rubey and Hubbert, 1965, p. 471.)

The detachment of the several slices of the Taconic allochthon at successively more western sites as its emplacement progressed is probably explained by continuing subsidence of the geosynclinal trough west of the Vermont-Quebec geanticline, during a relatively short time in the late Middle and possibly early Late Ordovician (see Zen, 1967, p. 40, 68-69). As the geosynclinal trough and the upper surface of its sediments subsided, the steepest part of its eastern flank was extended westward away from the geanticline, and the slices were as rapidly detached from the newly steepened slopes. The first slices to arrive, at least, were emplaced in seawater (Zen, 1967, p. 67).

The foregoing interpretation of the mechanism of the Taconic slide does not imply a mutually exclusive choice between the pull of gravity and tangential shortening of the Earth's crust as primary causes of movement of the allochthon. The flotation provided by the pore fluids could make the difference between success or failure of sliding movements caused by either or both. Gravity seems most likely insofar as a root zone is unrecognized, suggesting detachment and sliding from an otherwise undisturbed source terrane. Gravity sliding is a necessary factor, regardless of possible crustal shortening in the root zone, because it is clearly unlikely that the Taconic allochthon was competent to transmit the stress necessary to thrust its forward portions (Cady, 1945, p. 578).

ANALOGUES OF THE TACONIC SLIDE

The tectonic setting of the Taconic slide suggests that slides produced by similar mechanisms may be found elsewhere. The deformation of the Taconic slide by the later, middle Paleozoic Acadian folds and thrusts suggests, however, that its analogues may not be clear where late structural features are much more complex than those of the Acadian orogen in New England and New York. Where complex late deformation is superimposed on early folds and slides, as in the Alps, the rocks can be restored only with difficulty to their position in the early regime, and the slides may be indistinguishable from conventional thrust faults of the late regime (see Davis, 1965, p. 465-466; Rubey and Hubbert, 1965, p. 472).

Almost a homologue of the Taconic slide is the slide beneath the "Taconic" klippen on the west side of the Appalachian-Caledonian geosyncline in western Newfoundland (Brückner, 1966; Lilly, 1964; Rodgers and Neale, 1963). The allochthon of eugeosynclinal rocks moved from the east during the Middle Ordovician and came to rest on Middle Ordovician miogeosynclinal rocks much as in New York and New England. The allochthonous rocks are preserved on both limbs of an Acadian anticlinorium homologous with the Green Mountain-Sutton Mountain anticlinorium, instead of predominantly in a synclinorium to the west. The root zone of this allochthon is evidently to the east of the belt in which the anticlinorium later formed, much as the root zone of the Taconic allochthon in southern Vermont is east of the Green Mountain-Sutton Mountain anticlinorium. A possible homologue of the Vermont-Quebec geanticline is a welt containing Precambrian basement and/or lower Paleozoic rocks, proposed in the vicinity of the root zone (Rodgers and Neale, 1963, p. 724), although critical stratigraphic convergences and unconformable overlaps are not known. A gravity high, the axis of which is a little east of the root zone (in the Long Range Mountains in southern

Newfoundland—Innes and Argun-Weston, 1967, p. 80), repeats the relations of the gravity high that coincides with the Vermont-Quebec geanticline east of the Green Mountain-Sutton Mountain anticlinorium in southern Vermont.

The best known slides of the Appalachian-Caledonian belt, as well as those first to be called *slides* (Bailey, 1910, p. 593), are in Scotland (Fleuty, 1964). Several classic recumbent folds and slides in the Grampian Highlands (Rast, 1963, p. 125-138; Watson, 1963, p. 240-244) compare with the recumbent folds in the thick deposits in the eugeosynclinal zone east of the Vermont-Quebec geanticline in the Taconic region. Moreover, their metamorphic relations are comparable, and it seems likely that fluids expelled during regional metamorphism (Chinner, 1966) as well as during compaction helped movement (see Charlesworth and Lambert, 1964, p. 840-842; Rast, 1963, p. 138-140; Watson, 1963, p. 244-245).

In the Alps the Prealpine and Pennine nappes, which were emplaced in the late Mesozoic and early Cenozoic and were subsequently deformed during extremely complex folding and thrusting in the Cenozoic (van Bemmelen, 1964, p. 97-122; Trümpy, 1960, p. 897-898), compare significantly with the Taconic allochthon and related recumbent folds. The Prealps compare with the Taconic klippe, and the Briançonnaise platform whence they came is an analogue of the Vermont-Quebec geanticline (see Trümpy, 1960, fig. 1, *A*, p. 853, 854-855). Gypsum in widespread lower Mesozoic miogeosynclinal rocks on this platform and elsewhere perhaps provided water that assisted movement (see Trümpy, 1960, p. 893; Rubey and Hubbert, 1965, p. 472). The Pennine nappes, analogous to the major recumbent folds east of the Taconic region, are rooted in eugeosynclinal rocks.

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