Structural Geology of Silurian and Devonian Strata in the Mid-Hudson Valley, New York:

Fold-Thrust Belt Tectonics in Miniature

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Stephen Marshak [1]

Geological Survey

NEW YORK STATE MUSEUM

MAP AND CHART SERIES NUMBER 41

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Albany, New York 12230

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CONTENTS

ILLUSTRATIONS

ABSTRACT

When geologic exploration of the central Hudson Valley began in the early part of the 19th century, investigators recognized a narrow belt of deformed Silurian through Lower Devonian fossiliferous carbonate and clastic rocks between the Catskill Mountains front and the Hudson River. The basic stratigraphic divisions proposed in the early studies are still used today, though in somewhat modified form. These units represent the deposits of sequential transgressions of an epeiric sea over the previously peneplained Taconic orogen. They have provided type assemblages of North American shallow-water marine fauna and have been used as a source for cement and crushed stone since the 1820s.

In recent years, it has become clear that this belt of deformed Silurian-Devonian strata is a miniature post-Taconic fold-thrust belt, in which strata have been shortened above a detachment fault. The shortening is manifested by a west-verging thrust system and associated fault-bend and fault-propagation folding. The thrust sheets are deformed internally by cleavage and mesoscopic folds and faults. First-order folds in the belt have a wavelength of 200-800m.

Particularly good exposures of the structure of the belt are available in the roadcuts of Route 23 near Catskill and in various quarries along the Hudson Valley. The present report provides maps and cross sections of parts of the belt near the city of Catskill and the city of Kingston, discusses the geology of these regions, and provides a field guide to selected outcrops.

Evidence from the fold-thrust belt near Catskill suggests that there may be two major detachment horizons: one at or near the Taconic unconformity (which separates the Silurian-Devonian sequence from the Middle Ordovician turbidite sequence previously folded during the Taconic orogeny) and the other at depth in the Ordovician sequence. The upper detachment has been named the "Rondout detachment" and the lower one, the "Austin Glen detachment." Movement on the Austin Glen detachment resulted in folding of the Taconic unconformity, the Rondout detachment, and the thrust system that originates at the Rondout detachment.

North of Kingston, the fold-thrust belt trends N-S to N15°E. Post-Taconic deformation can be readily recognized only in strata above the Taconic unconformity; the pin line of the belt, i.e., the boundary in plan view between the shortened region of the fold-thrust belt and the unshortened foreland, lies east of the Catskill front. The principal belt in which these strata are exposed is now only about 2 km wide because erosion has removed them from the Hudson River eastward. Post-Taconic deformation, however, must have affected the region east of the Hudson River and probably extended across the present position of Taconic Mountains. At the city of Kingston, the fold-thrust belt changes in trend and character. To the southwest of Kingston, structures trend more northeasterly, detachments propagated further westward into the foreland, and there is greater shortening of the post-Taconic sequence.

It is possible that structures southwest of Kingston represent the northeastern limit of Late Pennsylvanian Alleghenian foreland deformation, and that structures north of Kingston represent the southern limit of Middle Devonian Acadian foreland deformation. If so, the change in structural trend at Kingston is an intersection orocline created where the younger northeast-trending deformation belt overprinted the older north-trending belt. The zone of overlap, which lies in the city of Kingston, contains non-cylindrical folds, out-of-sequence thrusts, accommodation faults, multiple sets of slip fibers on bedding surfaces, and overprinted cleavages.

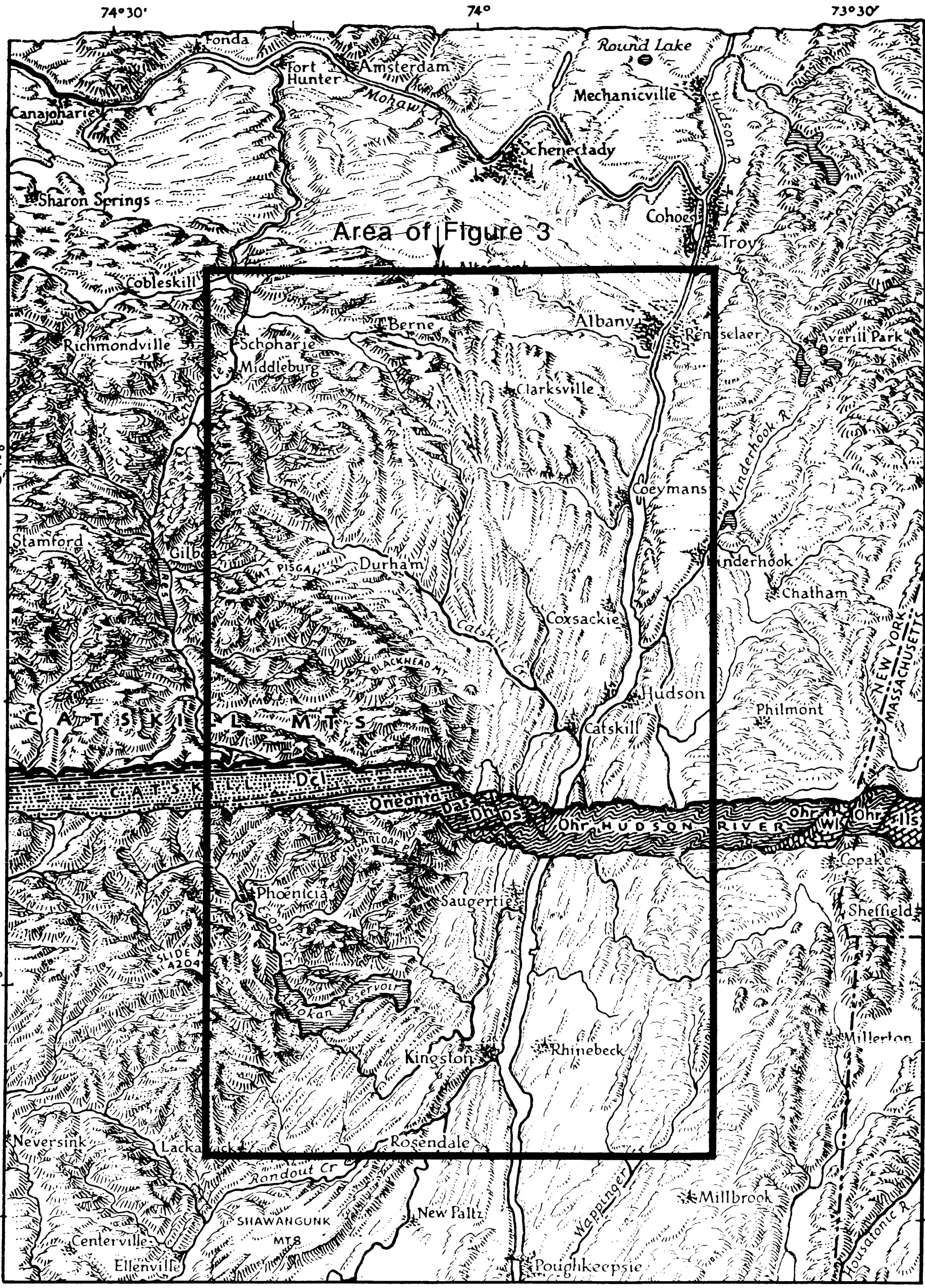


Figure 1 Block diagram of the Mid-Hudson Valley region. *Ils*, Inwood limestone (Precambrian); *Wls*, Wappinger limestone (Cambro-Ordovician); *Ohr*, "Hudson River" (Cambro-Ordovician) shales; *DS*, Upper Silurian and Lower Devonian beds; *Dh*, Hamilton beds (Middle Devonian); *Das*, Ashokan beds (Hamilton age); "*Oneonta*", Kiskatom beds (Hamilton age); *Dcl*, "Catskill" beds (Upper Devonian). Scale, five miles to seven-sixteenths of an inch. (After Berkey)

INTRODUCTION

The Mid-Hudson Valley, which encompasses the lowlands between the Catskill Mountains and the Taconic Mountains (Figure 1), lies entirely within the Appalachian orogen (Figure 2). Most of the valley is underlain by Cambrian through Middle Ordovician strata (Figures 1, 3) that were deformed during the Middle Ordovician Taconic orogeny, but in a narrow belt near the west edge of the valley, and in two small outliers (Mount Ida and Becraft Mountain) east of the Hudson River, Cambrian-Ordovician strata are unconformably overlain by Silurian through lower Middle Devonian rocks. The Silurian-Devonian sequence is itself deformed; this sequence contains post-Taconic folds, faults, and fabrics that are similar in style to those found in many foreland fold-thrust belts. Thus, the Mid-Hudson Valley region was affected by post-Taconic fold-thrust belt-style deformation. For convenience, Marshak (1986a) introduced the term "Hudson Valley fold-thrust belt" (HVB) to refer to the north-south to N15°E-trending segment of the post-Taconic fold-thrust belt that extends between the cities of Kingston and Albany (Figure 3). HVB structures are best displayed in the Silurian-Devonian sequence, but the processes that formed these structures must also have affected older strata of the valley.

Rocks and structures of the HVB have fascinated generations of geologists during the century and a half since they were first noted by W.W. Mather's (1838, 1843) geologic survey of eastern New York. Today the belt still serves as a natural laboratory where students study the fundamentals of field geology and where researchers seek clues to the complex history of the Appalachian Mountains. Silurian-Devonian rocks of the HVB are also an important economic resource because they are quarried extensively for use in the manufacture of cement and crushed stone.

The present report summarizes work by Marshak (1986a) and Marshak and Tabor (1989) on the structural geology of Silurian-Devonian strata in the HVB. It also provides a synopsis of the exploration of these rocks, their stratigraphy, and their value to industry. Accompanying this report are large-scale geologic maps and cross sections (Plates 1-3) that cover two areas: the region west of the town of Catskill and the region surrounding the city of Kingston. A field guide to key outcrops in the HVB is also included. This field guide is an updated version of one prepared by Marshak (1986b). The guide offers an excellent opportunity to examine structural characteristics of fold-thrust belts, to study the development of cleavage in carbonate rocks, to study classic North American Lower Devonian faunas, and to gain insight into the tectonics of the Appalachians.

Figure 1: Block sketch of the central Hudson Valley and adjacent regions photocopied from Goldring (1943; after Berkey) at 90 percent of original scale. The cross-section interpretation differs from that described in the present report. Note the linear valleys and ridges in the interval between the Hudson River and the Catskill Mountain front. The Berkshire Mountains are the highlands along the New York-Massachusetts border, and the Taconic Mountains are indicated by the plateau extending west from the Berkshires to a position about 8 miles east of the Hudson River. Figure 8a is an SAR image of the same general area.

ACKNOWLEDGEMENTS

I wish to thank Yngvar Isachsen for his interest in this work and for inviting me to write this report, and William Rogers for guiding this report through production. I also wish to thank the many geologists who have been kind enough to share ideas concerning the geology of the Hudson Valley and fold-thrust belts during the past decade, particularly T. Engelder, J. Epstein, P. Geiser, D. Kent, N. Ratcliffe, L. Rickard, D. Rowley, R. Waines, D. Wise, and Z. Zadins, and the students who worked with me in the area, particularly J. Tabor, D. McEachran, S. Bhagat, and S. Wilkerson. Comments and reviews by W. Rogers, E. Landing, Y. Isachsen, L. Rickard, P. Geiser, and T. Engelder improved the manuscript. A portion of this study was supported by NSF grant EAR-84-007785.

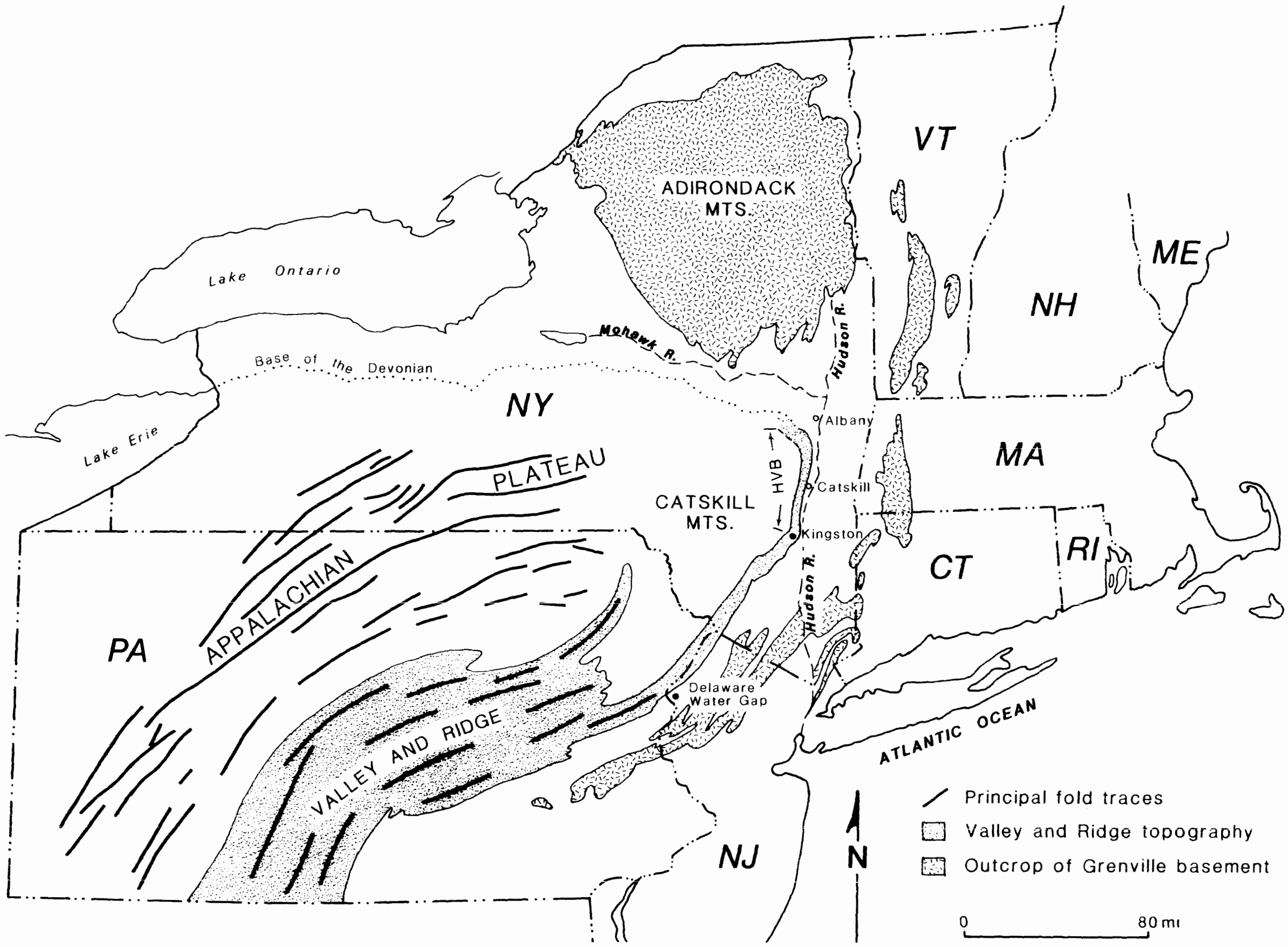


Figure 2: Position of the central Hudson River Valley with respect to the Pennsylvania Valley and Ridge and the Appalachian Plateau. Part of the stippled band in the central Hudson Valley region coincides with the outcrop belt of Silurian and Devonian strata in the HVB; the ends of this interval are shown. The heavy lines in the region of the Appalachian Plateau and the Pennsylvania Valley and Ridge indicate the traces of folds. The base of the Devonian in central New York State is indicated by the dotted line.

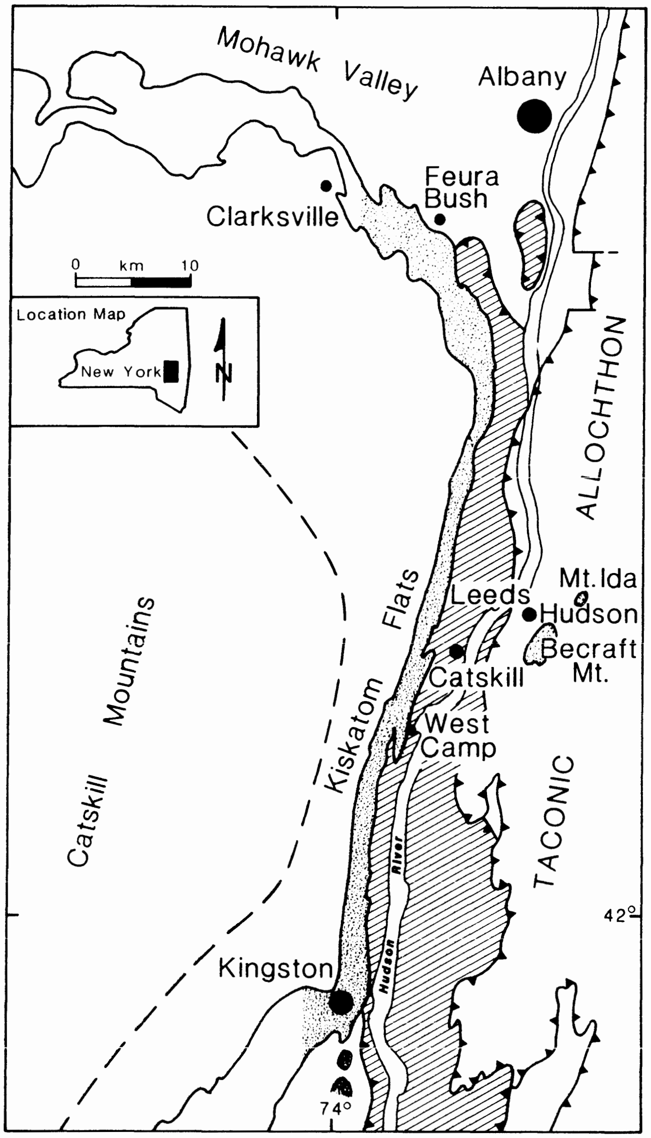


Figure 3: Localities in the central Hudson River Valley. The toothed line in unpatterned areas is the western edge of the Giddings Brook Slice, the traditional western limit of the Taconic Allochthon as outlined by Fisher and others (1970). The diagonally ruled area is the Livingston slice described by Rickard and Fisher (1973). The boundaries of this slice, marked by teeth pointed inward, are exposed edges of the slice; otherwise the edges are buried. Younger, autochthonous, Middle Ordovician Martinsburg Formation forms the unpatterned area north and southwest of the Livingston slice. The stippled area represents outcrop of Silurian and Lower Devonian strata of the HVB. The limits of Silurian and Lower Devonian outcrop outside the HVB are delimited by the thin lines. The Kiskatom Flats is the belt between the Silurian-Devonian outcrop belt and escarpment that forms the Catskill Mountain Front. The Catskill Mountain front is indicated by the dashed line. The dark mottled areas south of Kingston are the Quassaic Group outcrops. See figures 1 and 8a for physiography.

HISTORY OF EXPLORATION AND GEOLOGIC STUDY

Exploration of the Hudson River Valley region by Europeans dates back to the discovery voyage of Henry Hudson in 1609. Prior to that time, the valley was the home of Algonquian-speaking Indian groups. In the years immediately following Hudson's voyage, only fur traders and adventurers plied the river, but by the latter part of the century European settlers (initially the Dutch and later the French, Germans, and British) established prosperous towns along the river banks and inland (Johnson, 1976). Huge land grants were made to individuals, and this resulted in the development of a modified feudal system of tenant farming in the valley by the middle of the 17th century (Goldring, 1943, quoting Clark, 1936-1938; Johnson, 1976). Dutch control of the valley lasted until 1664 at which time the region became the domain of the British crown. With the transfer of government, the British honored earlier land grants, and the lot of tenant farmers did not improve through most of the 18th century.

During the first half of the 19th century a diverse economy developed in the valley, involving farming, shipping, whaling, tanning, lumbering, brickmaking, cement-making, and heavy industry. The Hudson River became a major avenue of commerce. In the second half of the century, tourism in the valley became popular. City dwellers migrated up the river to escape the heat of summertime New York, and the images of their lighthearted holidays are preserved in several paintings of the Hudson River School. By the beginning of the 20th century, many farms returned to scrub and the population of the region decreased because the rocky soils and steep slopes of the Hudson River Valley never made good farm land, and the railroad displaced river sloops as a favored mode of transportation. The economy has revived in the past few decades as new types of industry draw a new generation of settlers to the valley.

The 1800s mark the beginning of geologic study of the Hudson River Valley. Much of the field work carried out during these early years was done under the auspices of regional surveys organized by the New York State Geological Survey. W.W. Mather (1838, 1843) provided the first comprehensive report on the geology of the Hudson River Valley in his summary of the results of the geologic survey of the "First District" (eastern New York). At the time of Mather's report, the Helderberg Group had been defined and the distinct Silurian-Devonian formations found in the valley were recognized, though many of the names used to refer to these formations are different from those used today. Mather's (1843) report includes what are probably the first descriptions of the structures found in exposures of the Silurian-Devonian strata. He identified locations at which structures (which he termed "contortions") were exposed and provided simple cross-sectional sketches of selected folds and faults.

William Morris Davis, the famous Harvard geologist, was fascinated by the structures affecting the Silurian-Devonian strata in the Hudson River Valley. Davis (1882, p. 20) referred to the belt containing these rocks as the "Little Mountains" and poetically contrasted them with the Catskill Mountains to the west, "The one is a great wall painted old red and dull green; the other is like a miniature where every stroke is individual and full of meaning." In the late 1800s, Davis led field trips along the new rail line following the bank of Catskill Creek in Austin's Glen. The rail line, which formed part of the route from the port at Catskill to the grand Mountain House Hotel near North Lake at the crest of the range, has been removed, but the grade and the outcrops still exist. Davis's descriptions and illustrations of the Little Mountains are quite detailed (Figure 4; Davis, 1882, 1883a, 1883b, 1883c). What seemed to be of particular interest to Davis was the observation that folded and faulted rocks occur at a low elevation in the valley whereas the adjacent high peaks of the Catskill Mountains were carved from flat-lying strata. This contrast indicated to Davis that regions of high topography do not always coincide with regions of complex deformation. In addition to mapping near Catskill, Davis also mapped the Kingston area (Figure 5; Davis, 1883c) and Becraft Mountain (Davis, 1883b).

Geologic study of the HVB by the New York Geological Survey continued during the latter part of the 19th century and through the first half of the 20th century. The most notable of the studies from this period was conducted by the young N.H. Darton (1894a; 1894b; 1894c), who in later years became renowned for his work in Arizona. Darton was assigned by Major Powell, then director of the U.S. Geological Survey, to assist James Hall, then director of the New York State Geological Survey, in the mapping of exposures of Silurian-Devonian strata in Albany and Ulster counties in order to complete the geologic map of New York State. Darton, in the course of two field seasons, created geologic maps, cross sections, block diagrams (Figure 6), and photographs of many localities in the HVB and along the Mohawk Valley. Geologists looking at Darton's photographs today can only dream about being able to examine the clean outcrops at quarries that he had access to, because although the specific outcrops illustrated in Darton's papers can still be found, they are now covered by a century's growth of vegetation.

Geologists of the Geological Survey (a part of the New York State Museum) mapped two 15-minute quadrangles that include portions of the deformed Silurian-Devonian belt (Coxsackie Quadrangle by Goldring, 1943; Catskill Quadrangle by Ruedemann, 1942, and Chadwick, 1944) and provided careful description of the structure and stratigra-

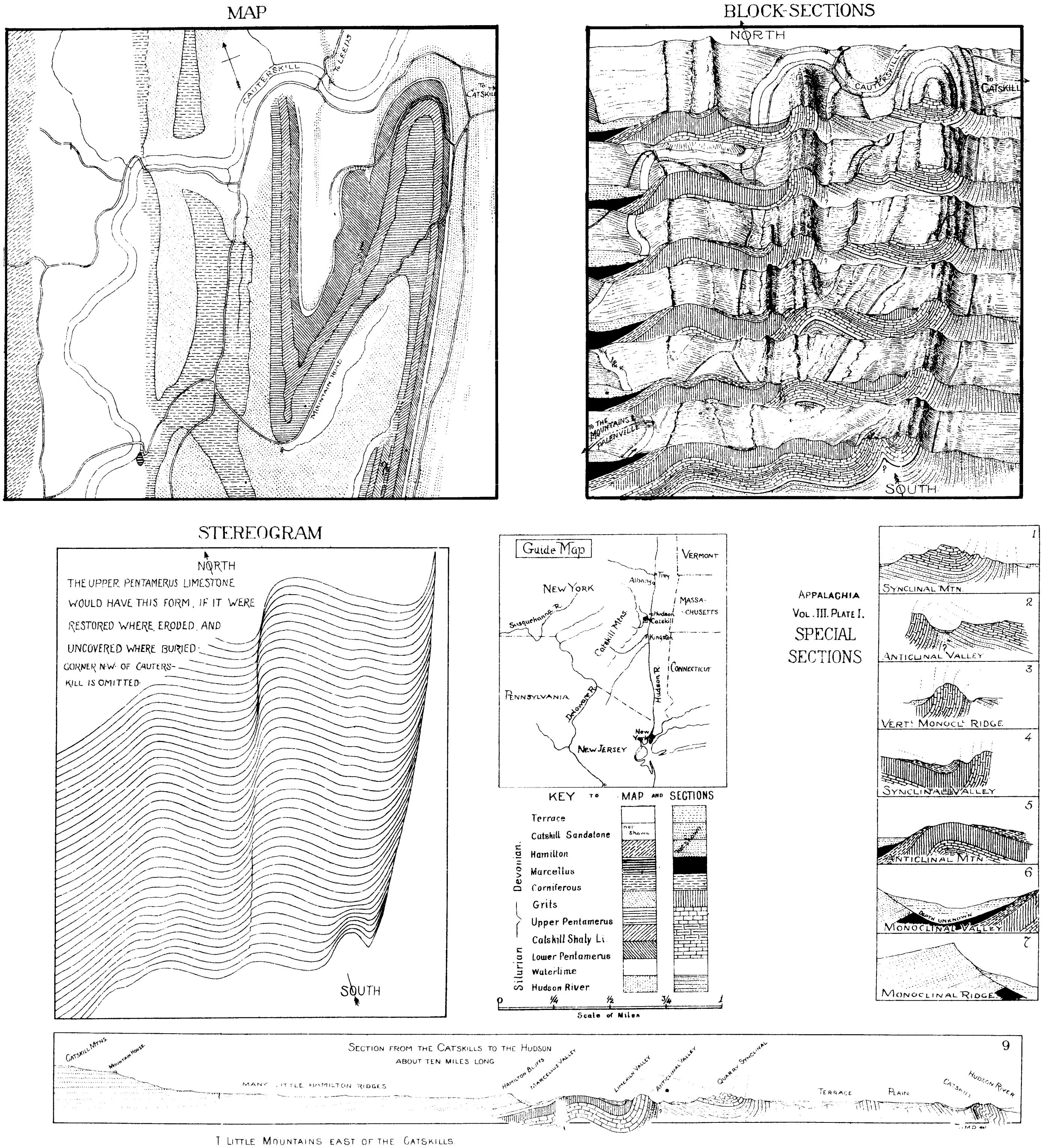


Figure 4: An example of early structural analysis in the Hudson River Valley region, which helps to visualize the structural geometry of the area. Note that the faulting in the area (as shown in Plates 1-3 of this report) is virtually ignored. This is a mosaic photocopy of maps and diagrams of the Quarry Hill area photocopied from Davis (1882) most at 80 percent original scale, long cross section at 60 percent.

phy in these quadrangles. Survey/Museum-associated geologists also made local studies of specific structures in the belt (Chadwick, 1910; 1913; Chadwick and Kay, 1933; Van Ingen and Clark, 1903). Van Ingen, a professor at Princeton University, began a tradition of student field study in the belt, and one of his pupils, H.R. Wanless, completed a massive master's thesis on the geology of the Rosendale cement district (Wanless, 1921) before embarking on a distinguished career as a stratigrapher at the University of Illinois. Others who described the region during this time include Shaler (1877), Schuchert and Longwell (1932), and Berkey (1933).

In the second half of the 20th century, the belt has continued to be used as a teaching showcase for geology students; field trips and mapping classes are frequently run in the region by professors at colleges and universities in the Northeast. Perhaps hundreds of students visit the belt every year. Several theses have been completed on rocks in the area (Babcock, 1966; Leftwich, 1973; Zadins, 1983; Marshak, 1983; Tabor, 1985; McEachran, 1985; Bhagat, 1988), and several authors have provided field guides to the region (e.g., Waines and Hoar, 1967; Heyl and Salkind, 1967; Johnsen and Schaffel, 1967; Sanders, 1969; Ratcliffe and others, 1975; Marshak and Geiser, 1980; Marshak, 1986b; 1989; Marshak and Engelder, 1987; Epstein and Lyttle, 1987). In recent years, a few journal articles have focused on structural problems of the belt (Murphy and others, 1980; Marshak, 1986a; Marshak and Tabor, 1989), but it is surprising that much more work has not been done in the belt, considering its value as a laboratory for the study of fold-thrust belt tectonics.

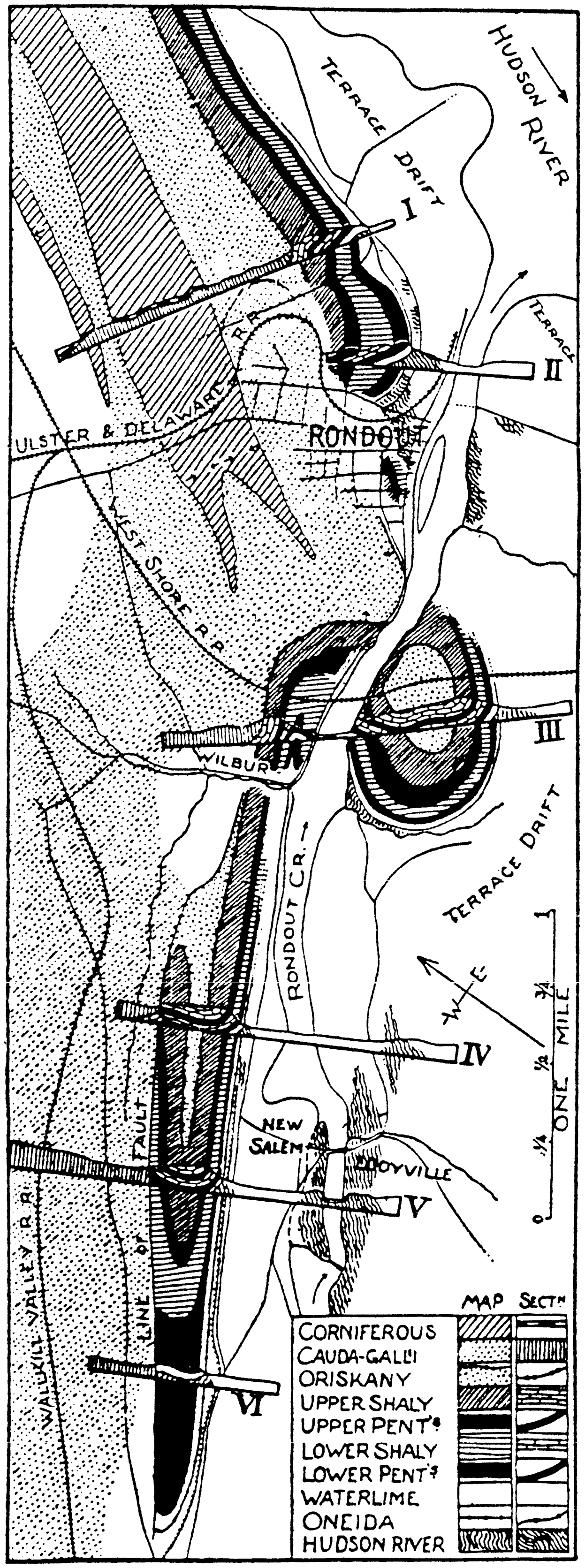


Figure 5: An early geologic map in the Wilbur-Rondout area near Kingston. Photocopied from Davis (1883c) at full scale.

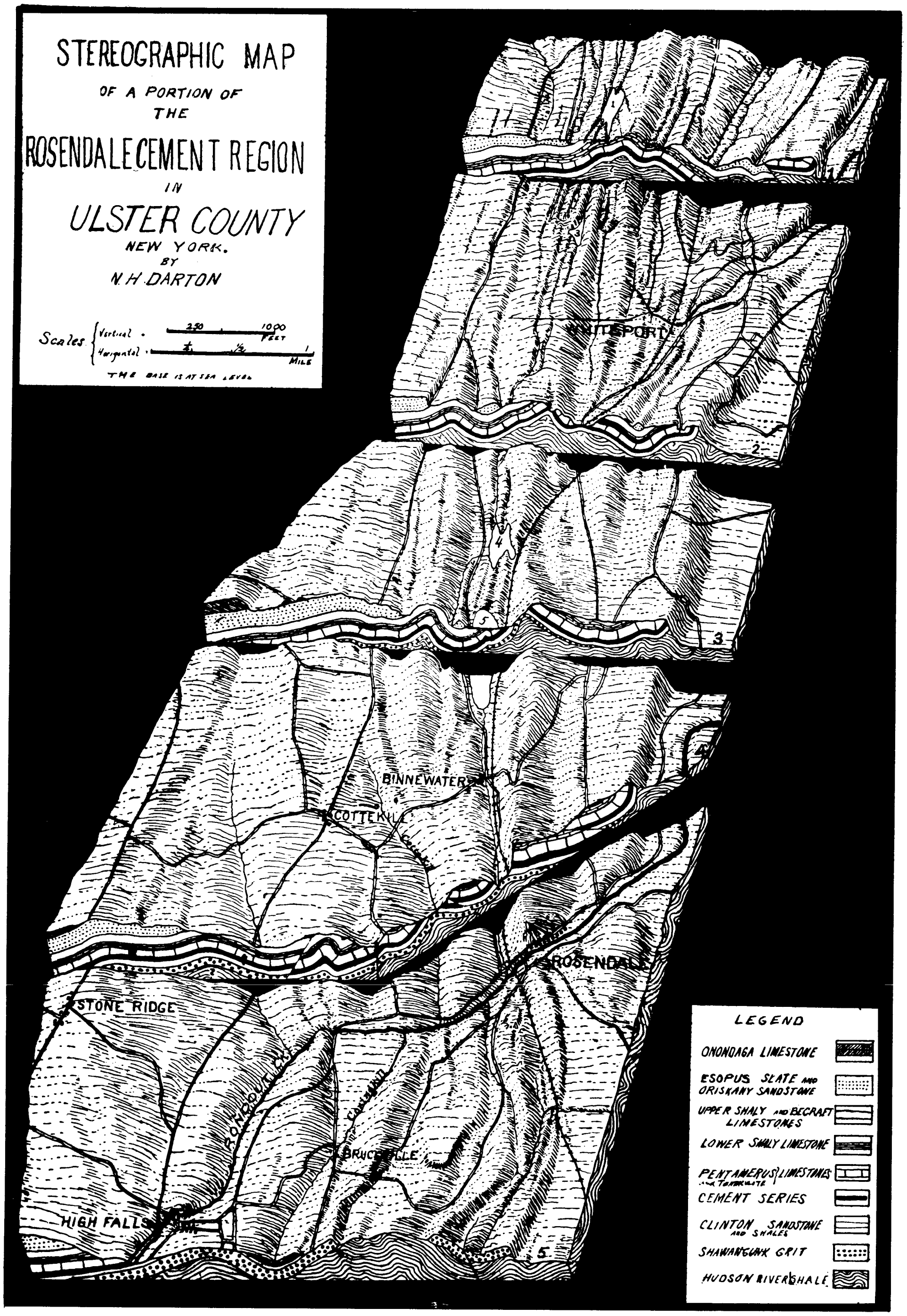


Figure 6: A "Stereographic Map" of the Rosendale cement region by Darton (1894a). Photocopied at full scale.

GEOLOGIC SETTING OF THE HUDSON VALLEY

A traverse across the valley at the latitude of Catskill intersects three distinct north-south-trending geologic terranes (Figure 3; Figure 7). These are described below in order from east to west.

(1) *Taconic Allochthon:* The Taconic allochthon is composed of sheets of deeper-water (slope) facies of Cambrian-Ordovician strata thrust westward over shallower-water (shelf) facies of roughly the same age (e.g. Zen, 1972). The emplacement of the thrust sheets of the Taconic allochthon represents deformation of the Lower Paleozoic passive-margin sedimentary wedge (the Paleozoic "geosyncline" in older literature) of eastern North America during the Middle Ordovician Taconic orogeny. This orogeny is thought to be a consequence of the collision between North America and an offshore volcanic island arc subsequent to the eastward subduction of the intervening ocean floor (Chapple, 1979; Rowley and Kidd, 1981). The Taconic allochthon is bounded at its base by a detachment that is itself folded, but regionally is gently dipping.

The allochthon is internally divided into several distinct thrust sheets (see Ratcliffe and others, 1975). Traditionally, the westernmost sheet of the Taconic allochthon was considered to be the Giddings Brook slice, and the western edge of the Giddings Brook slice (indicated on Figure 3) was considered to be the western edge of the allochthon. Work by New York State Geological Survey geologists (Rickard and Fisher, 1973; Rickard, in progress) suggests, however, that Ordovician strata bordering the Hudson River in the central Hudson Valley are also allochthonous. Fisher and Rickard have defined an additional sheet of the Taconic allochthon called the "Livingston slice," which straddles the Hudson River and is indicated by the diagonal pattern in Figure 3. The Livingston slice, whose western edge is buried beneath Silurian-Devonian strata, is composed of the Middle Ordovician Austin Glen and Mount Merino Formations. The Austin Glen is composed of slightly metamorphosed clastic strata including "graywacke" (argillaceous lithic arenite), sandstone, shale, and conglomerate. The Mount Merino is composed of shale or slate. Graded beds are common in the Austin Glen Formation. In many outcrops, the beds have been affected by west-verging folding and faulting. The majority of the tectonic structures found in outcrops of the Austin Glen and Mount Merino Formations of the Livingston slice are considered to be manifestations of the Middle Ordovician Taconic deformation (e.g. Bosworth and Vollmer, 1981) even though these rocks must have been affected by more recent deformation events as well (Ratcliffe and others, 1975).

The Livingston slice is underlain by autochthonous or para-authochthonous Ordovician slate and sandstone of the Martinsburg Formation. Detailed analysis of graptolite faunas demonstrates that the Martinsburg is younger than the Austin Glen Formation. Strata of the Martinsburg, where exposed north and south of the Livingston slice, were also deformed during the Taconic orogeny. Directly south of Kingston, the Ordovician sequence lying to the west of the Livingston slice includes a thick wedge of sandstone (locally reddish colored), "graywacke," and conglomerate that composes the Quassaic Group of the Marlboro Hills (see Waines and others, 1983).

(2) *Hudson Valley Fold-Thrust Belt:* The contact between Ordovician rocks (Livingston slice, Giddings Brook slice, or autochthonous sequence) and the overlying Silurian-Devonian sequence is an unconformity, angular in most localities, that is commonly called the *Taconic unconformity*. Silurian through lower Middle Devonian strata above the unconformity, as well as the unconformity itself, are deformed. This deformation indicates that the Hudson Valley region was subjected to a post-early Middle Devonian (therefore, post-Taconic) deformation event. Structures displayed in

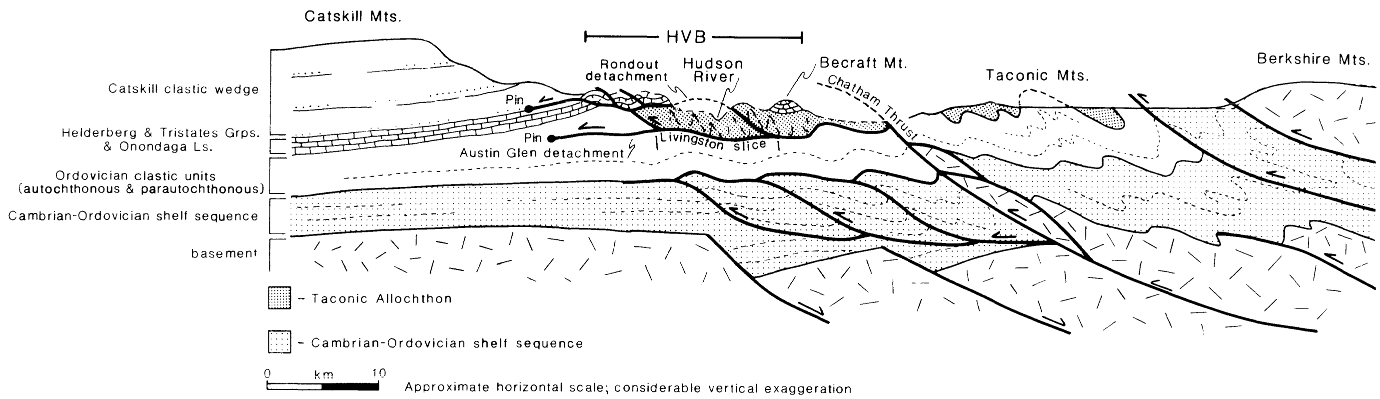


Figure 7: Schematic cross section of the central Hudson Valley region at about the latitude of Catskill. Heavy lines are faults, thin lines symbolize bedding traces. Faults may be of three ages with reactivation possible on some of them; uncertainties about the sequence of faulting remain, however.

outcrops of the Silurian-Devonian sequence are typical of fold-thrust terranes.

As noted earlier, the region of the Mid-Hudson Valley between Kingston and Albany in which post-Taconic fold-thrust structures are found has been called the Hudson Valley fold-thrust belt (HVB). Because the Taconic unconformity and, by implication, the Ordovician strata below the unconformity, are affected by the post-Taconic fold-thrust deformation event, the term "HVB" is not strictly equivalent to the Silurian-Devonian outcrop belt, although HVB structures are most apparent in Silurian-Devonian rocks. The occurrence of fold-thrust structures in outliers east of the Hudson River (Becraft Mountain and Mount Ida) serves to emphasize that the deformation creating the HVB involved the entire Hudson River Valley region and that, prior to erosion of Silurian-Devonian strata east of Becraft Mountain, post-Taconic fold-thrust deformation also involved the region that is now the Taconic Mountains. Therefore, the HVB overlaps and involves the Taconic allochthon (Figure 7). Unfortunately, it is difficult to distinguish Taconic from post-Taconic structures in outcrops of pre-Silurian strata. Ratcliffe and others (1975) have identified such structures in the vicinity of Mount Ida (see description for Supplemental Stop SA in the field guide) and have emphasized the probability that faults in the Taconic Mountains (e.g. the Chatham thrust) which cross cut Taconic slaty cleavage are post-Taconic and might be coeval with the structures found in Silurian-Devonian rocks.

The HVB can be traced as far north as Feura Bush (near Albany), where Silurian-Devonian strata are truncated by erosion along the Mohawk Valley (Figure 2). At Feura Bush, the Silurian-Devonian outcrop belt turns northwest and follows the Mohawk Valley. HVB structures in Silurian-Devonian strata can be traced westward about 8 km from Feura Bush to Clarksville, where shear zones are present in the Union Springs Shale (Bosworth, 1984) and folds affect the Onondaga Limestone. West of Clarksville, Silurian-Devonian strata are flat-lying. The HVB extends as far south as Kingston. At Kingston the trend and character of fold-thrust structures involving the Silurian-Devonian strata change. A northeast-southwest-trending fold-thrust belt extends southwest from Kingston across the northwest edge of New Jersey, then bends at the Delaware Water Gap to merge with the Valley and Ridge Province of Pennsylvania. The name HVB is not applied to the fold-thrust belt between Kingston and the Delaware Water Gap, for reasons described later in this report (see Marshak and Tabor, 1989).

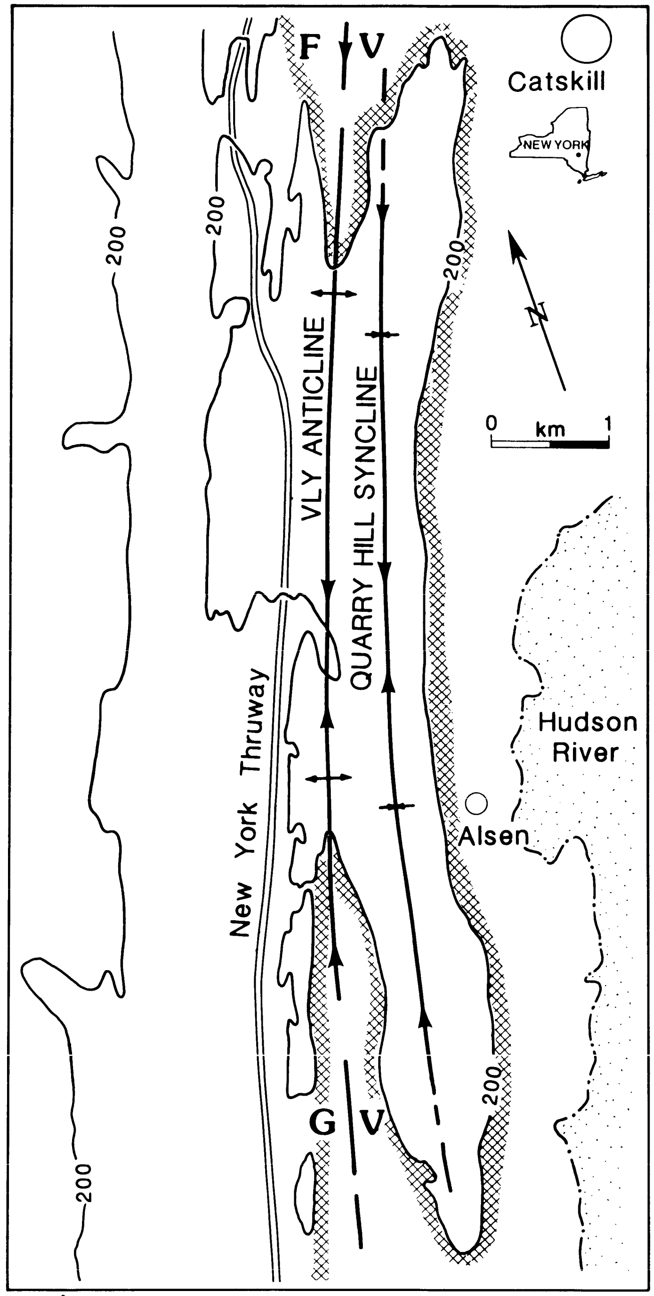
(3) *Kiskatom Flats:* The name Kiskatom Flats is used for the narrow plateau that lies between the HVB and Catskill Mountain front at the latitude of Catskill. The Flats are underlain by gently westward-dipping marine siltstone (Mount Marion Formation) of the Middle Devonian Hamilton Group. These strata form the base of the Catskill clastic wedge, a thick foreland basin sequence of clastic strata shed from the Acadian Highlands (which lay to the east) in Middle and Upper Devonian time. Above the Mount Marion Formation are the nearly flat-lying Middle Devonian non-marine sandstone, shale, and conglomerate beds of the Middle Devonian Genesee through West Falls Groups that form the high peaks of the Catskill Mountains.

PHYSIOGRAPHY OF THE SILURIAN-DEVONIAN OUTCROP BELT IN THE HVB

Almost all of the deformed Silurian-Devonian strata of the HVB lie in a narrow (2-3 km wide) belt west of the Hudson River (Figure 3). Only two small outliers of these rocks, Becraft Mountain and Mount Ida, lie east of the river. The Silurian-Devonian outcrop belt west of the river is bounded on the east by a 5-20 m-high cliff called the Helderberg Escarpment, and is bounded to the west by a 10-30 m-high ridge called the Hooge Berg (Figure 8a; see Chadwick, 1944). East of the Helderberg Escarpment is a low area underlain by the Ordovician Austin Glen Formation (Ohr in Figure 1); in most localities, the Taconic unconformity is exposed at the base of the escarpment. West of the Hooge Berg is a narrow plateau, the Kiskatom Flats, underlain by nearly flat-lying strata of the Middle Devonian Hamilton Group. The western edge of the Kiskatom Flats is the Catskill Mountain Front. West of the front, the Catskill Mountains rise to an elevation of nearly 1300 m.

The Silurian-Devonian outcrop belt of the HVB west of the river is, topographically, a miniature valley and ridge province (Figure 1) in which the axes of the ridges and valleys parallel structural grain. North of Kingston, structures trend north-south to N15°E, and thus the axes of the valleys and the crests of the ridges trend north-south to N15°E. The easternmost ridge of the belt was called "Kalk Berg," meaning lime hill, by the early Dutch settlers. Typically, valleys mark the eroded cores of anticlines, with strata dipping away from the valley axis, and, at many localities, synclinal cores form ridges. Some valleys, however, occupy synclines, and others mark the traces of thrust faults. Most folds in the HVB plunge gently, and thus most valleys terminate at the cusp of a horseshoe (Figure 8b). Ridges tend to be asymmetric, with one side being a near-vertical cut at a high angle to the strata, whereas the other side is a dip slope.

(a)



(b)

Figure 8: Illustrations of HVB physiography. (a) Sidescan Radar image (SAR) of a portion of the HVB southwest of Catskill. Note the valley and ridge topography. The Hooge Berg and the Helderberg Escarpment are labeled. (b) Map of the 200-foot contour interval, which traces out the shapes of the Quarry Hill syncline and the Vly anticline (from Marshak, 1986a). Note how the plunge directions of the folds are reflected by the horseshoe shape of the valleys. GV = Great Vly, and FV = Fuyk Valley.

ECONOMIC GEOLOGY OF SILURIAN-DEVONIAN STRATA IN THE HVB

Rocks of the Silurian-Devonian sequence have served humanity for centuries. In prehistory, certain formations of this sequence, especially the Onondaga Limestone and the Kalkberg Formation, were well known among Indian tribes of the New York area as a source of flint for tools and arrowheads; the flint was broken from the black chert nodules that weather out of these units. More recently, Silurian-Devonian strata are used as the raw material for the manufacture of cement, and the production of dimension stone and crushed stone.

The cement industry of New York State began in association with the construction of the Erie Canal in 1818 (Nason, 1894; Hartnagel and Broughton, 1951) and the Delaware and Hudson Canal in 1824. At that time, it was discovered that impure dolostone, or "waterlime rock," of the Silurian Rondout Formation could be converted directly into a strong hydraulic cement that could be used to seal the walls and locks of the canal. The process of producing this "natural cement" simply involved quarrying the rock and burning the chunks in kilns to remove the CO_2. New York State bought the patent rights to the process in 1825, and numerous quarries were established in the Kingston-Rosendale district to extract those parts of the Rondout Formation which had the appropriate composition. Typically, kilns were constructed adjacent to quarries so that the raw rock did not have to be transported far; the cement was then carried to its destination by train or by barge. By 1840, sixteen cement plants with 60 operative kilns were in operation in the Hudson Valley (Hartnagel and Broughton, 1951).

The natural cement quarries of this era are remarkable feats of engineering. Most were roof-and-pillar mines (Figure 9) which followed waterlime beds downdip and along strike for hundreds of meters. Floor-to-ceiling distances ranged between 2 m and 20 m, depending on the thickness of the waterlime layer. At most localities, the strata contained two waterlime layers, and the mines were two-tiered. Quarrymen of the era were observant and were not misled by structure; where bedding was horizontal, the mines were horizontal, where bedding was vertical, the mines were vertical, where bedding was folded, the mines followed the form of the fold, and where the waterlime layers were repeated by thrust faults, mines were developed in each thrust sheet.

The history of the natural cement industry in the Hudson Valley followed a pattern similar to that of a gold rush. It was born in 1825, reached maturity in 1899, when almost five million barrels of cement were produced, and was almost dead by 1918, when only 10,000 barrels were produced

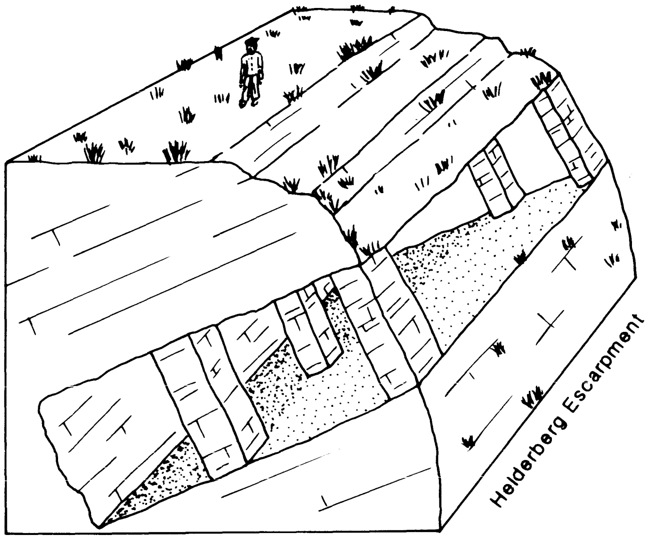


Figure 9: Block sketch of an inclined roof-and-pillar quarry in the Rondout Formation along the Helderberg escarpment, showing how the quarry operators followed the dip of beds.

(Hartnagel and Broughton, 1951). The natural cement industry has been revitalized in recent years because natural cement has properties that make it preferable to its successor, portland cement, for certain applications. For reasons of economy and safety, roof-and-pillar mining has not been practiced in recent decades. The waterlime is now separated from other rocks at open-pit portland cement quarries and is then processed separately. Roof-and-pillar mines of the 19th century still exist with the ruins of the large kilns next to them, but most are overgrown with brush and ivy and are hidden from view. Some of the abandoned mines have served as mushroom plantations and, more recently, as storage vaults for corporate records.

The natural cement industry shrank because portland cement, which is produced by fusing a mixture of limestone, sandstone, and shale in correct proportions, is cheaper to produce. Raw materials for portland cement can be obtained by quarrying the entire section of the Lower Devonian (the Helderberg and Tristates Groups), and, therefore, the quarries can be large open pits. Quality of the end product is controlled by monitoring the proportions of the different rock types placed in the kiln. The first portland cement plants were established in the Hudson Valley in 1881 near the town of Beacon and in 1883 near Kingston. Ultimately, cement companies built huge plants, some of which are still operating at Cementon, Becraft Mountain, Catskill, Connelly, East Kingston, Ravena, and South Bethlehem. The large quarries, which also produce crushed stone, provide excellent exposures of HVB structures.

DESCRIPTION OF STRATIGRAPHY

Detailed description of the stratigraphy and sedimentology of rocks in the central Hudson Valley has been presented by many authors (e.g., Goldring, 1943; Chadwick, 1944; Ruedemann, 1942; Rickard, 1962, 1989; Laporte, 1969; Sanders, 1969). The purpose of this section is not to review this literature exhaustively but rather to indicate the key characteristics of the Ordovician through lower Middle Devonian units of the HVB (Figure 10) that can be used to distinguish among units in the field and thus can be used as a basis for mapping. The description is based, in part, on suggestions by L.V. Rickard (oral communication, 1980). Excellent sketches of fossils in the units were provided by Goldring (1943) in a paper that has long been out of print; her sketches are reprinted in the Appendix.

Ordovician clastic rocks below the Taconic unconformity comprise strata of the Normanskill Group [Austin Glen (Figure 11a) and underlying Mount Merino Formations] and strata of the Martinsburg and Quassaic Formations. Normanskill strata are believed by Rickard and Fisher (1973) to be allochthonous and compose the lowest, westernmost Taconic thrust sheet which they named the Livingston sheet (Figure 3). The Austin Glen Formation is more widespread and better exposed than the Mount Merino Formation. The Mount Merino is composed of green, gray, and black shale with interbedded black chert, and the Austin Glen is composed of greenish-grey argillaceous lithic arenite ("graywacke") interbedded with shale. The graywacke beds are of various thicknesses, are commonly graded, and locally contain lenses of pebble conglomerate. In outcrops dominated by shale, the shale shows a weak slaty cleavage, but, in those dominated by graywacke, the shale contains only pencil structure.

Southwest of Kingston and north of Feura Bush the Middle Ordovician clastic rocks beneath the Taconic unconformity are probably part of the Martinsburg Formation (Waines, oral comm., 1985, Epstein and Lyttle, 1987, Rickard, oral comm., 1988). Martinsburg rocks are similar in appearance to those of the Normanskill Group and can be difficult to distinguish from them without a detailed knowledge of graptolites. Directly south of Kingston, the Middle Ordovician Quassaic Formation (resistant sandstone, shale, conglomerate) underlies a line of north-south ridges (Marlborough and Illinois Mountains) that extends southward for nearly 40 km. At the northern end of this line is Hussy Hill, which is within the Kingston study area. The boundary of the Quassaic Formation outcrop belt shown on Plate 3 is taken from an unpublished map by Fisher. Waines and others (1983) and Cunningham (1987) suggest that a west-verging thrust fault, named the Esopus fault, brought strata

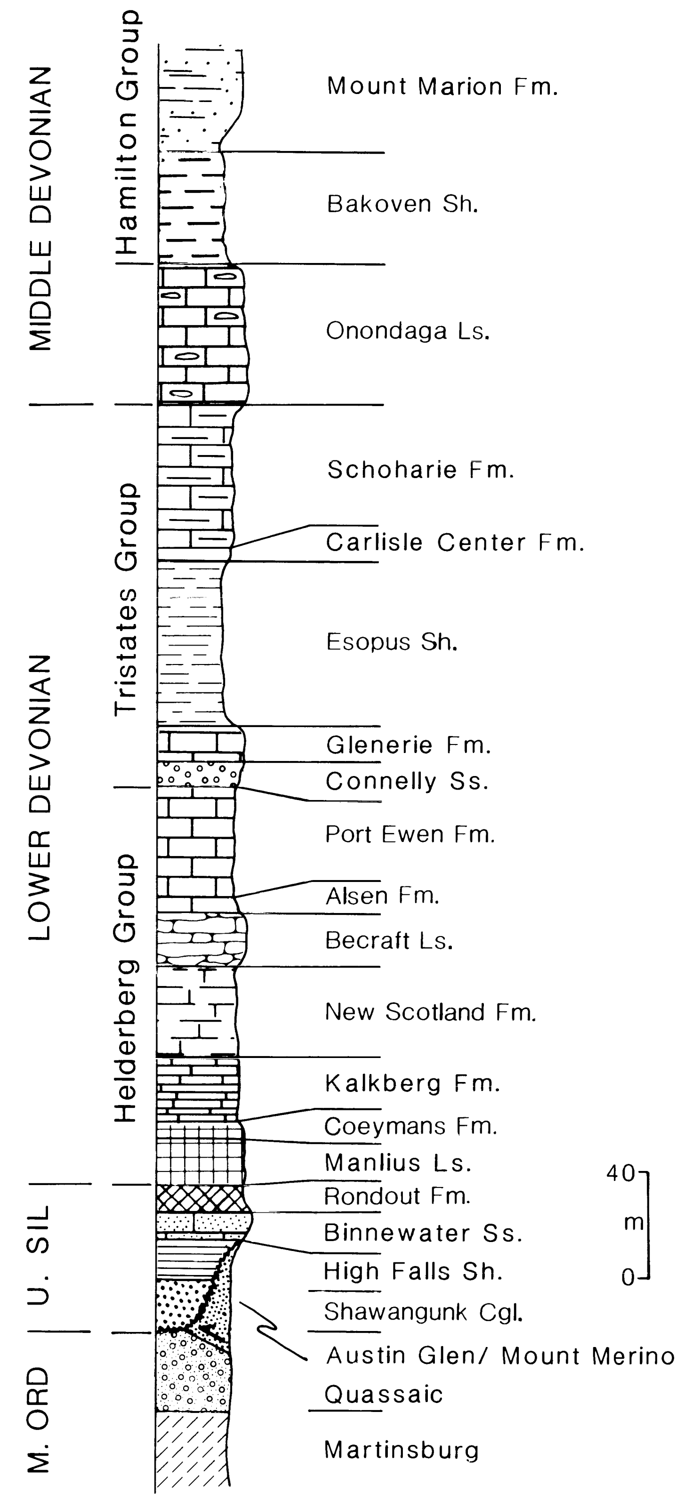
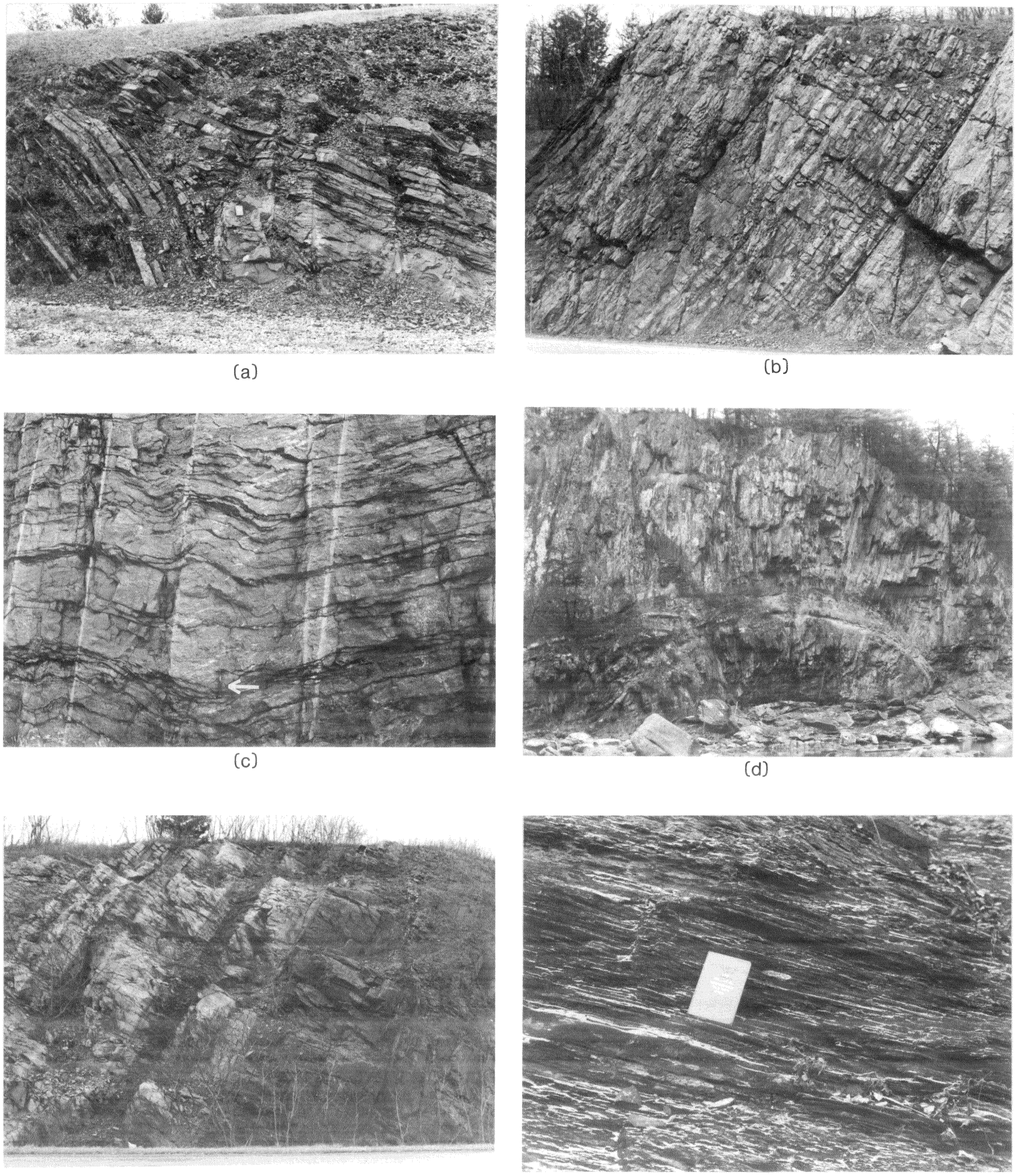


Figure 10: Simplified stratigraphic column of the units involved in the Hudson Valley fold-thrust belt of the central Hudson River Valley. Except on Plate 1, the Carlisle Center Formation is lumped with the Schoharie Formation.



(a) (b) (c) (d)

Figure 11 (e) (f)

of the Austin Glen Formation over that of the Quassaic along the east side of these ridges.

The only Silurian unit exposed in the Catskill area is the Rondout Formation. Along Route 23 northwest of Catskill, this unit is composed of orange-buff weathering non-fossiliferous, sandy dolomitic limestone. The interval characteristically has a 0.5-1.0 m thick, massive sandy dolostone at the base which is overlain by flaggy to shaly beds at the top. Thickness of this unit varies from 2.0 m to 6.0 m along Route 23, but most of the variation probably reflects tectonic thickening by folding and fault imbrication. The Rondout thickens rapidly to the south of Route 23 by the addition of a basal sandstone member called the Fuyk Sandstone, which is well exposed in the Fuyk Valley west of Quarry Hill just north of Route 23A. The Fuyk, which contains shale-chip conglomeratic lenses, only occurs for a short distance along strike before it pinches out.

In the Kingston area, the Rondout Formation consists of four members, named, from base to top, Wilbur (2.5 m of brownish-weathering, medium-grained, biostromal limestone), Rosendale (2 m of distinctive, rusty-brown weathering, non-fossiliferous, argillaceous dolostone), Glasco (3 m of dark-gray, thickly-bedded, fossiliferous limestone containing abundant *Halysites* chain corals and white calcite veins), and Whiteport (1.5 m of argillaceous, dull-gray to tan dolostone). The Whiteport and the Rosendale members are the units that were quarried for the production of natural cement. South of Kingston, the units thicken and additional Silurian formations are present. In Rosendale, the Silurian section includes the Binnewater Sandstone (cross-bedded locally dolomitic quartz sandstone), the High Falls Shale (red, gray, and green shale), and the Shawangunk Conglomerate (white quartzite pebble to cobble conglomerate). The Shawangunk thickens southward, attaining a maximum thickness of about 430 m, and forms the high cliffs of the Shawangunk Mountains that are an attraction to rock climbers. The distribution pattern of Silurian strata along the Hudson and Mohawk Valleys evokes a clear image of a Silurian sea transgressing to the northeast.

The Silurian strata of Hudson Valley are overlain by the Lower Devonian Helderberg Group, which includes seven thin formations (see the stratigraphic column, Figure 10, for approximate thicknesses). The Helderberg Group represents the deposits of two successive marine transgressions. The lower transgressive sequence includes the Manlius Limestone, Coeymans Limestone, Kalkberg Formation, and New Scotland Formation, and the upper sequence includes the Becraft Limestone, Alsen Formation, and Port Ewen Formation. Each sequence begins with a shallow-water limestone (lagoonal micrite or beach-environment grainstone), which, as the sea transgressed, was succeeded by progressively more argillaceous lime wackestones of the low-energy sub-wavebase environment (Rickard, 1962; Laporte, 1969; Sanders, 1969).

The lowest unit of the Helderberg Group is the Manlius Limestone, which locally consists of 20-30 cm thick micrite beds separated by biostromal beds. The micrite is very light-gray weathering, is thinly-laminated, and contains ostracode and tentaculite fossils. The ostracodes look like smooth black buttons if fully exposed or like black finger-nail clippings in profile, and the tentaculites look like tiny cones. The biostromal limestone is medium-dark gray and coarse-grained. On polished slabs, the biostromes appear as small (2-20 cm high) stromatoporoid or thrombolite build-ups surrounded by a wacke of lime mud and fossil fragments. In weathered outcrops, the biostrome layers look similar to limestone of the Coeymans, but the paper-thin laminated micrites are unique, and thus they serve as a distinctive marker for identifying the Manlius. The top of the Manlius can be mapped as the top of the highest laminated micrite.

The overlying Coeymans Limestone is composed of medium-coarse-grained, dark, mottled, gray lime grainstone and packstones. This unit contains the distinctive brachiopod *Gypidula coeymenensis* which characteristically appears on bedding surfaces as a white calcite rim with a "beak" or tooth protruding into the center.

The Kalkberg Formation (Figure 11b) is composed of fossiliferous (abundant brachiopods and bryozoa) argillaceous lime wackestone and packstone. The lower portion of this unit along Route 23 contains about half a dozen 5 cm-thick, continuous layers of black chert. The base of the Kalkberg can be mapped as the base of the lowest continuous chert.

Figure 11: Photographs of stratigraphic features in the HVB. (a) Austin Glen Formation, composed of graywacke layers interbedded with shale. In this exposure, the beds are folded by a large chevron fold. This outcrop is at the west end of the Rip Van Winkle Bridge; (b) Homoclinal interval exposing the contact between the New Scotland and Kalkberg Formations. The base of the New Scotland is defined by the thicker beds of alternating light and dark. Note highway reflector for scale; (c) Becraft Limestone, composed of lime grainstone beds separated by thin shale beds. Note the gentle folding, and the hammer for scale. Vertical lines are drill holes made during construction of the roadcut; (d) Exposure of Esopus Formation along a stream cut in Catskill Creek. Note the slaty cleavage. The cliff is about 35 m high; (e) Contact between the Esopus and Schoharie Formations in outcrop N1 on Route 23. Note the distinctive "black bed" near the base of the lighter Schoharie Formation; (f) Characteristic thinly laminated bedding of the Bakoven Shale, as exposed in Kaaterskill Creek, below the Route 23A bridge. Notebook for scale.

The Kalkberg grades upward into the New Scotland Formation.

The New Scotland Formation (Figure 11b) is composed of fossiliferous (abundant brachiopods and bryozoa) interbedded argillaceous buff-gray weathering lime wackestones and limy dark gray mudstones. New Scotland beds are generally more argillaceous than Kalkberg beds. The lower portion of this unit along Route 23 is a distinctive interval composed of alternating dark gray and light rusty-tan weathering beds that are about 15-25 cm thick (Figure 11b). The base of the New Scotland can be mapped as the base of this color-banded interval. In isolated weathered outcrops, the New Scotland is difficult to distinguish from the Kalkberg, and the two units were lumped as one map unit on the accompanying maps. Rocks of the New Scotland-Kalkberg interval are most readily distinguished from rocks of the Alsen-Port Ewen interval by the presence of the distinctive brachiopod *Leptaena* (see Appendix).

The New Scotland grades upward into the Becraft Limestone. The gradation occurs by thinning of muddy layers and by a progressive increase in the proportion of the outcrop that is composed of grainstone and packstone. The base of the Becraft was mapped at the stratigraphic level where light pinkish gray grainstone becomes the dominant lithology (>80%) of the outcrop. The lower part of the Becraft Limestone along Route 23 is composed of 10-30 cm-thick beds of light pinkish gray, wavy-bedded, medium- to coarse-grained lime grainstone. These rocks are composed largely of tightly cemented crinoid fragments. Beds are separated from one another by 2-5 cm thick layers of greenish-gray shale (Figure 11c), which characteristically possess slaty cleavage that is generally inclined at a low angle to bedding. The upper part of the Becraft Limestone lacks shale layers and tends to have thicker beds. Locally, upper Becraft contains abundant holdfasts of *Aspidocrinus*. In the vicinity of Kingston, the upper part of the Becraft Limestone is a distinctive massive interval (about 10 m thick) of light grey coarse-grained grainstone in which bedding planes are difficult to recognize.

The Becraft grades upwards into the Alsen Formation, which in turn grades upwards into the Port Ewen Formation. These units are lithically similar to the Kalkberg and New Scotland Formations, respectively. They are composed of argillaceous lime wackestone (the Port Ewen is muddier) and limy shale with layers or nodules of black chert, and have a mottled or banded appearance in weathered outcrop. The base of the Alsen is marked by the appearance of chert (chert does not occur in the underlying Becraft). Alsen and Port Ewen lithologies are difficult to distinguish from one another in weathered exposures, and they were mapped together as one map unit on Plate 2. In fresh exposures, such as in the Route 199 roadcut north of Kingston, the distinction between the two units is obvious; the Alsen is about 7 m thick and weathers dark gray whereas the Port Ewen is thicker (about 30 m) and weathers to a brown-gray. The Port Ewen is the highest unit of the Helderberg Group.

Overlying the Port Ewen in the Kingston area is the Connelly Conglomerate, a 1-3 m-thick interval of white quartzite pebbles in a matrix of brownish-orange sand. The Connelly does not occur in outcrops of the HVB north of Route 199 in Kingston. It is the lowest formation of the Tristates Group.

The Connelly is overlain by the Glenerie Formation, which is composed of black or dark gray hard cherty limestone. This unit grades into the Oriskany Sandstone to the west and south of the HVB. The Glenerie Formation is overlain by the thick Esopus Shale. This unit is dark gray or black and is composed of shale and siltstone with little if any carbonate cement. Typically, bedding planes in the unit are difficult to recognize in isolated exposures, and the dominant parting is usually a well-developed closely-spaced to slaty cleavage (Figure 11d). Bedding planes are indicated by color banding or variations in grain size where there is sufficient cross-sectional exposure. In places where the unit parts on bedding planes, the planes commonly display the trace fossil *Zoophycus*. *Zoophycus* looks like the impression of a mop head (Appendix) and represents the feeding traces of anchored worms. Examples of *Zoophycus* are particularly well developed on bedding planes in the Esopus adjacent to Route 199 near Kingston. Along Route 23 near Catskill, the upper 2 m of the Esopus Shale is composed of laminated beds of alternating siltstone and shale.

The next higher unit is the Schoharie Formation, which is composed of muddy light rusty-buff weathering, clay-rich dolomitic limestone. This unit has a distinctive banded appearance as a consequence of contrasts in color between adjacent beds (some beds weather lighter than others). Commonly, the Schoharie contains a well-developed, anastamosing, spaced cleavage. At many localities, there is a distinctive meter-thick layer of dark brownish-grey cherty limestone (Figure 11e), called the "black bed," near the base of the Schoharie. The interval containing the "black bed" is sometimes called the Carlisle Center Formation. The Schoharie Formation is the uppermost unit of the Tristates Group.

The Schoharie is overlain by the Onondaga Limestone. The Onondaga is light bluish-gray and very fossiliferous and contains abundant black nodular chert. Weathered outcrops of this unit have a distinctive knobby surface due to the differential solubilities of the chert and the limestone; the black chert layers stand in relief. The Onondaga is the basal Middle Devonian unit of the region.

The Onondaga is overlain at a sharp contact by the Bakoven Shale (finely laminated, marine black shale; Figure 11f) which in turn is overlain by the Mount Marion Formation (marine sandstone, siltstone, and shale). The Mount Marion is the youngest unit to clearly display the structures of the HVB (Ratcliffe and others, 1975; Murphy and others, 1980; Marshak, 1986a). These two clastic units are the lowermost units of the Hamilton Group, which is the lowest unit of the Catskill clastic wedge. Above the Mount Marion, nonmarine sandstone, shale, and conglomerate dominate the section.

STRUCTURAL FRAMEWORK OF THE HVB

This portion of the report provides a general description of key regional structural features found in the HVB. Additional detailed description accompanies discussion of individual map areas and is available in the Stop Descriptions of the field guide.

It was recognized by the turn of the century (e.g., Van Ingen and Clarke, 1903; Chadwick 1910) that the structures of the Silurian-Devonian strata in the Hudson River Valley were very similar in character to those of the Valley and Ridge Province of the central and southern Appalachian Mountains (Figure 2). These early reports clearly document the westward vergence of deformation; folds were recognized to be asymmetric with east-dipping axial planes, and the hanging-wall of thrust faults moved to the west. In modern parlance, the belt of Silurian-Devonian strata is a fold-thrust belt, a zone where the uppermost crust of the earth shortened in response to an applied compressive stress by the formation of thrust faults and related folds. As noted above, pre-Silurian strata of the Hudson Valley were also affected by fold-thrust belt deformation, but structures in these rocks are not the subject of this report.

W. M. Davis (1882) pointed out that the first-order folds of the HVB are significantly smaller than comparable structures of the central and southern Appalachian fold-thrust belts to the south. In some localities of the HVB, first-order folds are exposed in their entirety in a single outcrop. It is likely that the geometry and size of HVB structures is controlled, in part, by the magnitude of shortening that affected the area, by the relative thicknesses of mechanical units affected by the deformation, and by the ductility contrast between adjacent units. Carbonate units (e.g. Manlius, Coeymans, Becraft) of the HVB acted as relatively rigid struts whereas argillaceous units (e.g. New Scotland, Esopus, Bakoven) acted as the weaker members during the development of structures. The entire sequence of Rondout through Onondaga is effectively a rigid layer embedded between two ductile units (the Bakoven Shale above and the Austin Glen Formation below).

To understand the description of HVB structures, it is necessary to become familiar with the jargon used in recent years to describe fold-thrust belts (Figures 12a, 12b; see Boyer and Elliott, 1982). Thrust faults typically have a stair-step trajectory in profile (Figure 12b) and can be divided into *flats*, which follow bedding, and *ramps*, which cut across bedding (see Marshak and Woodward, 1988, for further description). An extensive flat from which ramps splay upward into the overlying strata is called a *detachment*. The line of intersection between a ramp and a bedding plane is called a *cutoff*, and the line along which a ramp intersects a flat is called a *fault bend*. The term "fault bend" can also be used to refer to changes in dip of a ramp. As rock of a thrust sheet moves past a fault bend, it must fold; otherwise, overlaps or gaps would develop between the hanging wall and footwall of the thrust. Such folds are called *fault-bend folds*. But fault-bend folds are not the only type of folds to develop in fold-thrust belts. In some localities, folds develop in advance of the actual fracture and formation of a fault plane; such folds are called *fault-propagation folds*. Folds may also develop where strata in a thrust sheet buckle and shorten above a detachment. Such folds, comparable to the wrinkles that develop in a rug as it slides across a floor, are called *detachment folds*. Folds may also form where rock is caught in a shear couple adjacent to a fault plane or between two faults.

An array of faults and associated folds related to movement and shortening above a detachment is called a *thrust system*. In general, thrust systems propagate toward the foreland by growth of a detachment into the foreland, and, thus, the older thrust faults lie in the hanging wall with respect to the younger thrust faults. As a consequence, older thrusts are themselves folded during movement on the younger thrusts. At some localities, ramps that cut up from a detachment do not merge again at a structurally higher detachment horizon (Figure 12c). Such an array is called an *imbricate fan* (Figure 12c). Where the ramps do merge at an upper detachment, the array of ramps is called a *duplex* (Figure 12c). Thrust sheets in a duplex are bounded above and below by faults. A thrust sheet that is surrounded by fault surfaces is called a *horse*. Implicit in the description of fold-thrust belts provided in this paragraph is the proposal that such belts are *thin-skinned* deformed terranes, meaning that the deformation found in fold-thrust belts does not extend below a basal detachment (Figure 12a).

Structural analysis of the HVB suggests that it is a *two-tiered* thrust system, i.e. the geometry of the belt can be explained as a consequence of shortening above two detachment horizons (Figure 13a). The upper detachment, called the Rondout detachment (Marshak, 1986a), occurs within or at the base of the Rondout Formation and thus is at or just above the Taconic unconformity. In the Route 23 roadcuts, this detachment horizon is marked in outcrop by a zone of small (2 cm-2 m amplitude) west-verging folds and intervals of duplexed beds developed in the shalier upper portion of the Rondout about 1-2 m above the unconformity. At the lati-

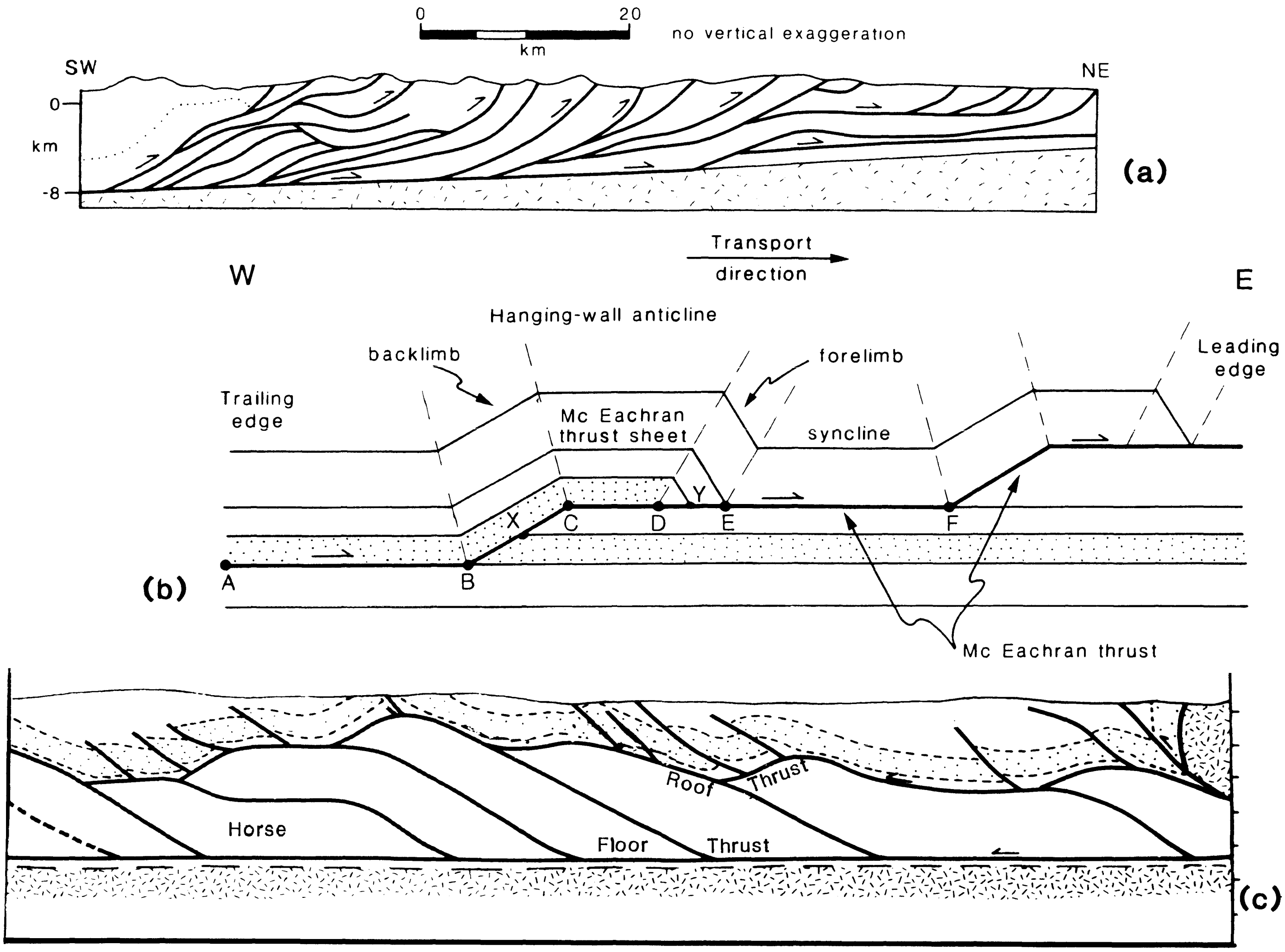
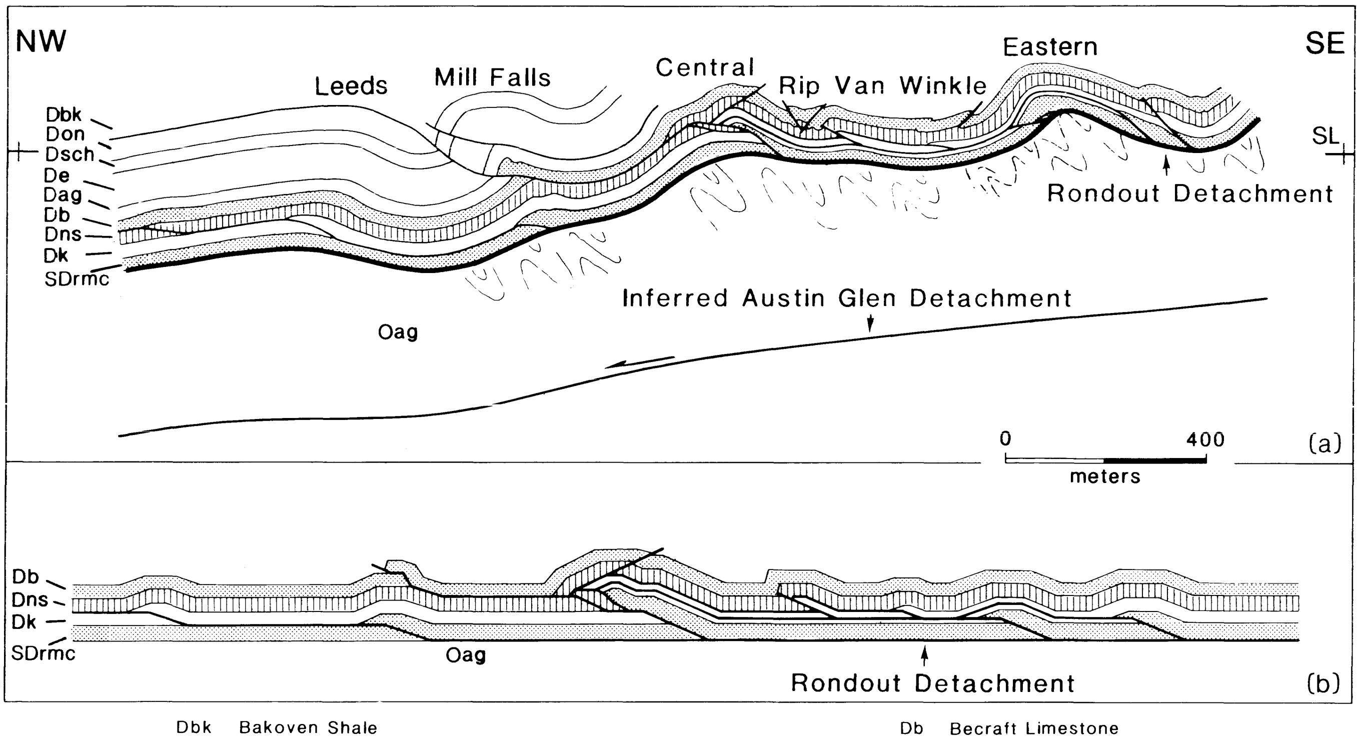


Figure 12: Illustrations of simple fold-thrust belt geometry. (a) Cross section of the Canadian Rockies (from Marshak and Woodward, 1988, after Price). This section illustrates an imbricate fan of thrust faults rooting in a basal detachment just above crystalline basement. (b) A stairstep thrust fault and associated fault-bend folds (from Marshak and Woodward, 1988). Footwall ramps are the segments of the fault that cut across strata of the footwall (e.g., segment BC). Hanging-wall ramps are segments of the fault that cut across strata of the hanging wall (e.g., segment DE). Footwall flats are segments that parallel bedding of the footwall (segments AB, CE, and EF) and hanging-wall flats are segments that parallel bedding of the hanging wall (segments AB, CD, EF). Cutoffs are the lines of intersection between a contact and a fault (e.g., points X and Y in cross section). (c) Illustration of the types of thrust systems (from Marshak and Woodward, 1988). The array of ramps in the unshaded region below the roof thrust is called a duplex and the system of thrusts that rise up from the roof thrust are an imbricate fan (note that imbricate fans do not always root in a roof thrust, as shown in part "a" of this figure).

tude of Catskill, Ordovician strata are not thrust over the Silurian-Devonian sequence. Therefore, the major thrust faults exposed in the HVB west of the Helderberg Escarpment in the Route 23 roadcuts (Plate 1) and the map area of Plate 2 are either ramps which rise from the Rondout detachment or are *out-of-the-syncline faults* which accommodate the room problem that develops in the core of a syncline as its limbs are squeezed together (Figure 14a). The Rondout detachment and the thrust faults and associated folds affecting the overlying strata are called the *Rondout thrust system*.

The Rondout thrust system and the underlying unconformity are folded by the first-order folds of the HVB. These folds have a wavelength of between 200 and 800 m, and their geometry controls the distribution of valleys and ridges in the belt. The folding of the Rondout detachment indicates that there must be another detachment structurally below the Rondout detachment. Because the Rondout Formation is the oldest post-unconformity unit, this lower detachment must be at some depth in the Ordovician sequence. The basis for this proposal is the fundamental hypothesis that in thin-skinned deformed belts, folding terminates at depth above a basal detachment.

The hypothetical detachment in the subsurface below the Rondout detachment is called the *Austin Glen detachment* (Marshak, 1986a). Above the Austin Glen detachment, the Ordovician sequence and the overlying Rondout thrust system were shortened and folded by post-Taconic deformation (Figure 13a). No evidence of ramps connecting the Austin Glen detachment to the Rondout detachment has been found in outcrops west of the Helderberg Escarpment. In this region, Ordovician strata are not thrust over the Silurian-Devonian sequence, and first-order anticlines are cored by Ordovician strata. Cross-sectional exposures of Ordovician-cored anticlines are present in a large quarry near East Kingston (see the field guide). At the Helderberg Escarpment, there are a few localities where Ordovician strata have been thrust a few meters over the basal beds of the Rondout Formation. One locality is in a quarry in East Kingston (see the field guide; McEachran, 1985), and another is a locality along Sprayt Creek near South Bethlehem (Darton, 1894b). Considering the lack of thrusting of Ordovician strata over Silurian-Devonian strata north of Kingston, it is possible that the folds involving the unconformity and the Rondout detachment are detachment folds formed by shortening above the Austin Glen detachment. If this shortening is removed, the Rondout thrust system displays familiar ramp-flat geometry (Figure 13b). To simplify drafting, the folds shown in Figure 13b are represented by "kink-style" geometry, i.e., folds are represented as domains of homoclinally dipping rock (dip domains) that connect at an angular hinge. It is not possible to determine to what extent the geometry of an individual megascopic fold in the HVB is a consequence of detachment folding above the Austin Glen



Dbk	Bakoven Shale	Db	Becraft Limestone
Don	Onondaga Limestone	Dns	New Scotland Formation
Dsch	Schoharie Formation	Dk	Kalkberg Formation
De	Esopus Shale	SDrmc	Rondout, Manlius & Coeymans Fms.
Dag	Alsen, Port Ewen, & Glenerie Fms.	Oag	Austin Glen Formation

Figure 13: Model of the two-tiered HVB. Upper tier refers to the thrust system above the Rondout detachment (after Marshak, 1986a). Lower tier refers to the folds developed above the inferred Austin Glen detachment. (a) Present configuration of the HVB thrust systems; (b) Configuration of the upper tier before the shortening above the Austin Glen detachment, modeled using kink-style fold construction. The cross section is longer than that shown in "a" because the folds affecting the Rondout detachment have been straightened out.

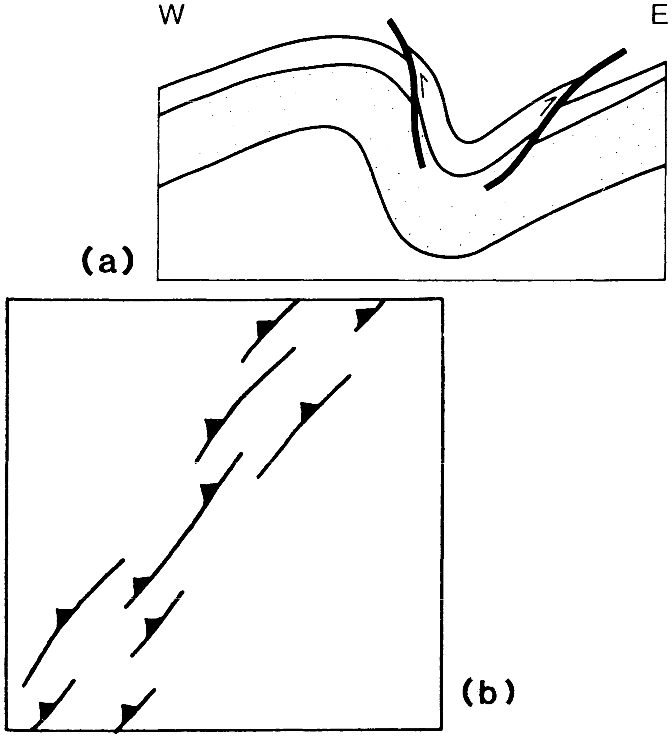


Figure 14: Sketches of fault geometries in fold-thrust belts. (a) Out-of-the-syncline faults, accommodate tightening of the core of a fold. One of the pair is a backthrust, i.e., its vergence is opposite the general vergence of the fold-thrust belt. (b) Sketch map showing relay pattern of thrust-fault traces. (From Marshak and Woodward, 1988.)

detachment, fault-bend folding, or fault-propagation folding in the Rondout thrust system.

The regional extent of the proposed detachments in the HVB is purely speculative at present. Figure 7 suggests that, prior to erosion, the folded Rondout detachment arched over the Hudson River's present course. It may have rooted in the Chatham thrust, as implied by Murphy and others (1980), in which case it passed under the outliers at Becraft Mountain and Mount Ida. This model incorporates the suggestion of Ratcliffe and others (1975) that post-Taconic movement occurred on the Chatham thrust and that this fault cut the basal detachment of the Taconic allochthon and the nonconformity between Grenville basement and the overlying Paleozoic sedimentary sequence. Alternatively, the Rondout detachment may have rooted in the interval between Mount Ida and Becraft Mountain and the Helderberg Escarpment. In this case, which is the hypothesis shown in Figure 7, the Taconic unconformity at the outliers is in the hanging wall, well above the Rondout thrust.

Figure 7 also suggests that the Austin Glen detachment may be an extension of the Livingston thrust, and thus, that movement on part of the Austin Glen detachment represents reactivation of the Livingston thrust. Movement on a detachment at greater depth in the Cambrian-Ordovician shelf sequence may be responsible for the arching of structures over the Hudson Valley (P. Geiser, written communication 1988). Finally, Figure 7 illustrates that Grenville crystalline rocks of the Berkshire massive are also allochthonous and that a duplex of basement horses may underlie the internal portions of the Taconic Mountains. Small slivers of this duplex are exposed along the Chatham fault (e.g., the Ghent block, Ratcliffe and others, 1975).

Mesoscopic folds (2 cm to 20 m wavelength) are visible at many localities in Silurian-Devonian strata of the HVB. In general, these folds appear to be a consequence of internal shortening by buckling of thrust sheets or of local shear couples. Internal shortening of thrust sheets is also indicated by widespread cleavage development in argillaceous rocks.

The map region around Catskill is the heart of the HVB. In Kingston, the fold-thrust belt structures change trend, and to the southwest of Kingston, structures trend more northeasterly, the fold-thrust belt widens, and Ordovician strata are thrust westward over the Silurian-Devonian sequence. Mapping of the Kingston area was conducted specifically to understand the origin of this change in orientation and character of the fold-thrust belt. Marshak and Tabor (1989) provide evidence that the bend in the fold-thrust belt at Kingston is an *intersection orocline*, which resulted from the overprint of a northeast-trending thrust system on a north-south-trending thrust system such that the second thrust system reoriented the structures of the first.

PRODUCTION OF THE MAPS AND CROSS SECTIONS

Accompanying this report are 3 plates. Plate 1 provides scaled outcrop diagrams of the Route 23 roadcuts west of Catskill, New York. The diagrams were drawn on a mosaic of photographs taken with a tripod-mounted camera (with a 50 mm lens) placed across the highway from the outcrop. To reduce distortion, each photograph overlapped its neighbor enough so that only the center third of each print was used in the mosaic. Geologic features were drawn on mylar overlays, and all sketching was done at the outcrop.

Plate 2 provides a map and cross sections of the HVB to the west of the city of Catskill. The map area includes a portion of the village of Leeds and straddles Catskill Creek and Route 23. (The original map was compiled in 1982 on a 1″ = 200′ topographic base with a 5-foot contour interval which was prepared by the New York State Department of Transportation (DOT) in preparation for the construction of Route 23. Blue line copies of the topographic base may be obtained from the DOT in Albany.) The best outcrops are along roads and streams, but enough outcrops exist in the woods to locate contacts and principal structures. Without the cross section provided by the Route 23 roadcut, however, the geometry of the thrust system might not have been understood. Outcrops are too numerous to permit their shapes to be portrayed on the map, but a symbol for bedding or cleavage attitudes is plotted at almost every outcrop, so the outcrop distribution can be determined roughly from the symbol distribution. In some parts of the map, measurement sites were located by pace and compass and by triangulation. Positions of most measurement points probably are accurate to 3 m, but in some places, positions are accurate only to 12 m.

The map of Kingston, Plate 3, was constructed on a 1:9600 topographic base, which is an enlarged composite of U.S. Geological Survey 7.5′ topographic quadrangles. These maps are available from the New York State Department of Transportation in Albany. The map area of Plate 3 includes portions of the Kingston East and Kingston West quadrangles. Mapping was done during 1984 and 1985 by the author and graduate students from the University of Illinois (John Tabor, David McEachran, Snehal Bhagat, and Phillip Kwiecinski). As on the Catskill-area map, outcrop distribution is indicated on the Kingston map by the distribution of attitude measurements. The inset on the map provides three cross sections at the map scale.

CATSKILL MAP AREA AND THE ROUTE 23 ROADCUTS

The structural geometry of the HVB, as it affects Silurian-Devonian strata, is best displayed in the roadcuts of Route 23 near Catskill (Plate 1). These roadcuts provide an almost complete cross-sectional view of the part of the belt that lies west of the Helderberg escarpment. The principal structures that can be directly observed in the roadcuts include:

(1) *Thrust Faults:* Thrust faults, which occur at a variety of scales and orientations in these exposures, locally have a ramp-flat geometry (Figure 15a). Faults that run along bedding planes are manifested either by a zone of fibrous calcite veins (Figure 15b) on the bedding plane, or by a zone of mesoscopic folding just above the fault (Figure 15c), or both. Fibers grow with their long axes almost in the plane of the fault and parallel to the transport direction. Examples of folding above a detachment occur at the west end of outcrop N2, just above the Rondout detachment in outcrops N5 and N3, and at the base of the Esopus Formation both in Catskill Creek at Mill Pond in the village of Leeds (upstream of Route 23) and just east of the junction between Route 23A and the New York State Thruway southwest of the town of Catskill (see field guide).

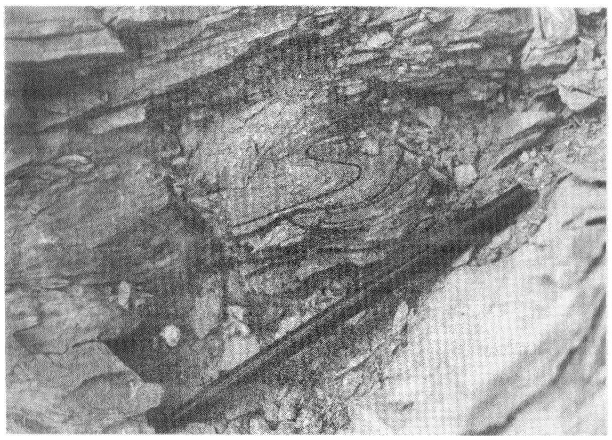
Thrust faults (ramps) that cut across strata are well exposed at several localities (Figure 15d). The largest stratigraphic throw visible in the Catskill area is in outcrop S2, where the Manlius Limestone is emplaced over the New Scotland Formation. In places, cross-strata faults are bounded by a breccia zone (Figure 15e) in which rock fragments occur in a matrix of vein calcite. Some of the cross-strata faults, such as the faults in outcrop N4, and the backthrusts in the Becraft Limestone of outcrop N3, are probably out-of-the-syncline faults, i.e., faults that displace strata in both directions from the core of a syncline as the fold tightens. Others, such as those of outcrop N2, are ramps that cut upsection from a detachment horizon. In outcrop N2, fault bends can be directly observed; the bends are bordered by thick lenses of calcite spar. Faults in outcrops N2 and S2 bound horses (lozenge-shaped bodies of rock that are completely surrounded by faults) that are stacked one upon the other to create an antiform. In argillaceous lithologies, faults may be bounded by a zone of intensified cleavage, in which cleavage is inclined at a relatively low angle to the slip plane (Figure 15f).

An observer comparing outcrops N2 and S2 may be struck by the contrast in the structural geometry of these two outcrops (Figure 16). This contrast may exist because a lateral ramp (a thrust fault that cuts upsection along strike) developed in the interval now occupied by the highway.

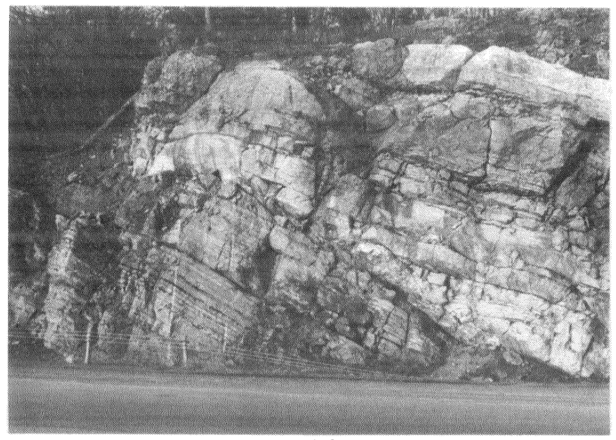
(2) *Folds:* Folds occur at two scales in the HVB. First-order folds, which control the map pattern of units and the topography, have amplitudes in the range of 50-120 m and wavelengths in the range of 200-800 m (e.g., the fold shown in Figures 11d and 17a). The map and cross section (Plate 2) show ten first-order folds across the HVB at the latitude of Catskill (these are named on the map). Individual folds can be traced along strike for distances of up to several kilometers (Plates 2 and 3), but they are arranged in a relay array along the length of the HVB. The term *relay array* implies that there are roughly the same number of folds across the width of the belt at most localities; thus, as a single fold dies out along strike another one develops to the east or the west (Figure 14b). Some of these folds, such as the Central anticline, are fault-bend folds (see Figure 11b, and the roadlog for Supplementary Stop B). Others, such as the Rip van Winkle anticline exposed in outcrop N2, probably are fault-propagation folds developed in advance of a throughgoing thrust (see field guide). Some of the folds, such as the Tollgate, Thruway, and Eastern folds, may be detachment folds resulting from shortening above the Austin Glen detachment. First-order folds in Silurian-Devonian rocks of the HVB are typically doubly plunging with plunges of up to 12°

(a)

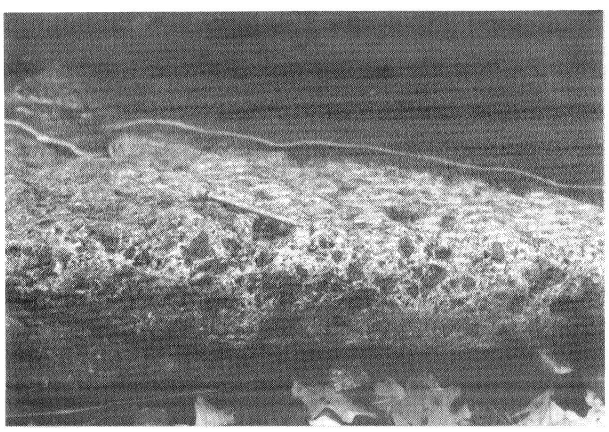
(b)



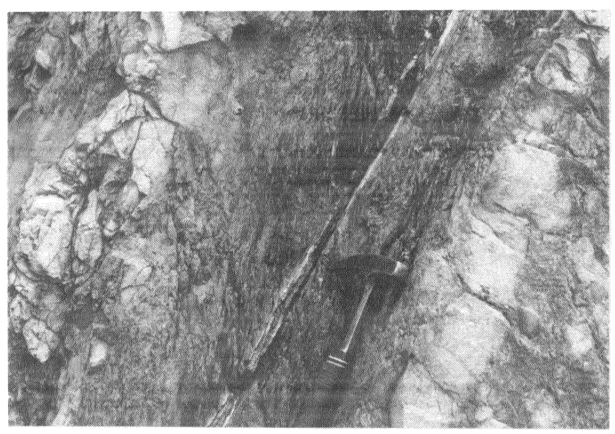
(c)



(d)



(e)



(f)

Figure 15: Photographs of mesoscopic features associated with faults in the HVB. (a) Mesoscopic ramp-flat geometry displayed by a fault stepping up through the New Scotland Formation at the west end of Route 23 outcrop N2, next to Catskill Creek; (b) Fibrous calcite veins that formed on a bedding-plane slip surface. The long axis of the fibers indicates the direction of slip, and the imbrication of fiber sheets indicates transport direction; (c) Small fold involving a shaly interval directly above a bedding-parallel detachment; (d) Cross-strata fault in outcrop N4 (Plate 1) bordered by a large pod of sparry calcite and local breccia; (e) Breccia lens adjacent to the fault at the base of the Esopus Shale in the Mills Falls anticline in Catskill Creek, upstream of Route 23; (f) Zone of strong cleavage bounding a calcite-fiber slip plane in a very argillaceous bed of the Kalkberg Formation. The sense of inclination of the cleavage indicates that the hanging wall moved up-dip. Note the refraction of cleavage in the less argillaceous bed below the shear zone.

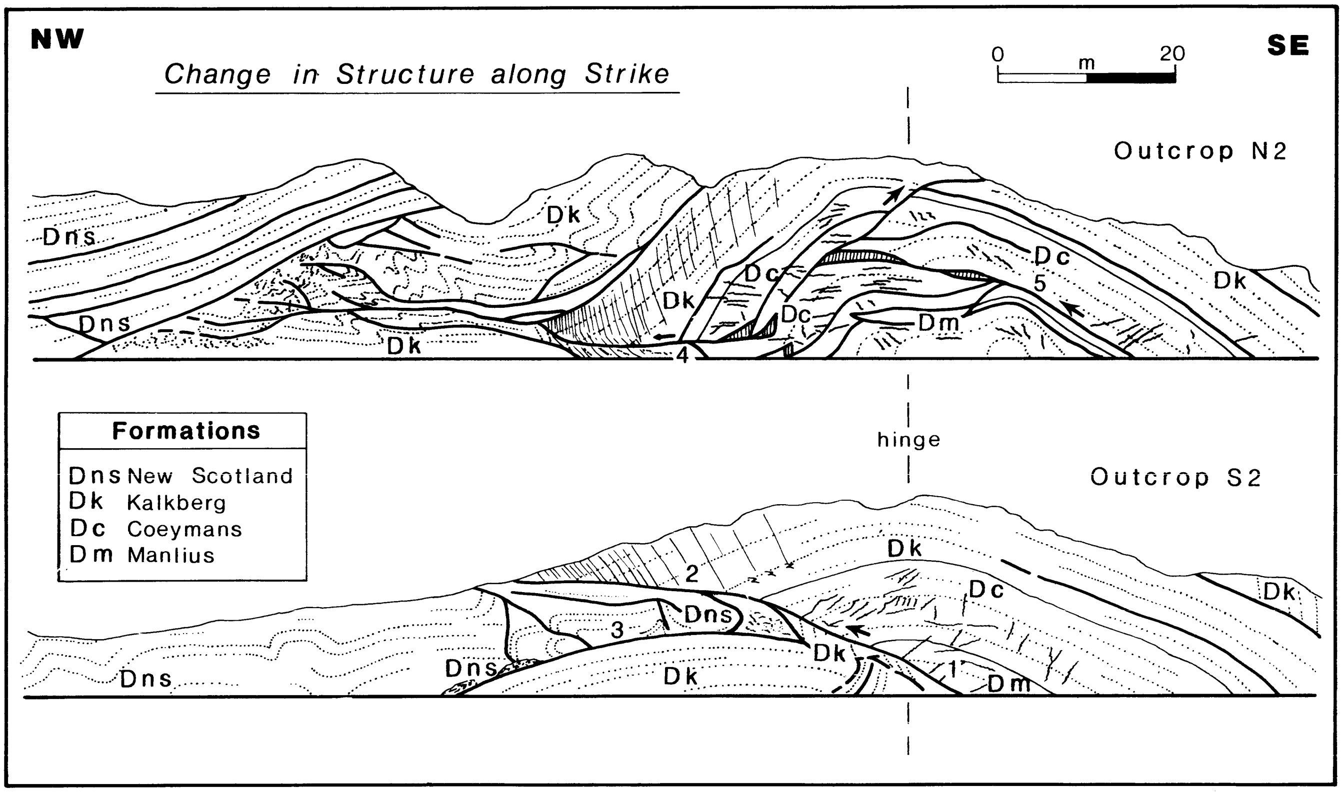


Figure 16: Contrast in structural geometry between the Central anticline exposure of outcrop N2 and that of outcrop S2 (after Marshak, 1986a). The sketch of the S2 exposure has been reversed so that it shows the correct vergence. Significant faults are numbered. The relationships among faults are described in the text.

and are somewhat conical in form; a given fold resembles a canoe because it is broad in the center and tapers toward the ends. Some first-order folds locally display more complex geometry with limbs that, at a given elevation, contort along strike from gently dipping to overturned (e.g., the northwest limb of the Central anticline). The crestline trace of the folds (the line separating east dips from west dips) is sinuous, and an individual fold trace may vary from a trend of north-south to a trend of N25°E.

In addition to the first-order folds, mesoscopic folds occur at many localities in the belt. Some of these represent second-order buckles in the core area of larger synclines (e.g., the folds in the core of the Tollgate syncline; Plate 2). Some reflect shear of the wall rock adjacent to faults (e.g., Figures 15c; 17b; 17c), or are simply small detachment folds above local faults (as visible on the east limb of the Central anticline in outcrop S2, Plate 1). Some mesoscopic folds develop to accommodate the internal strain in horses. The style of mesoscopic folds varies widely and depends on the lithology being folded; mesoscopic folds range in style from open buckles, to box folds, to tight chevron folds. The roadlog provides additional illustrations of different types of folds.

3) *Cleavage:* Cleavage is developed at many but not all localities in the HVB (see Marshak and Engelder, 1985). The distribution of cleavage is controlled by lithology and by structural position. Shale formations (e.g. Esopus) and argillaceous limestone formations (e.g. Kalkberg, New Scotland, Alsen, Port Ewen, and Schoharie) are more susceptible to cleavage development than purer limestone formations (e.g. Becraft, Manlius, Coeymans). Cleavage tends to be more strongly developed on the steep western limbs of anticlines; in fact the western limbs of some folds are severely thinned by cleavage development. Cleavage is also strong in the wedge-shaped region near the intersection of two faults, as exemplified by the strong cleavage found at the tip of a horse in the Kalkberg Formation on the northwest limb of the Central anticline. Cleavage also tends to be stronger in the rock adjacent to a fault. Typically, cleavage is spaced and is defined by an array of domains composed of concentrations of insoluble residue (quartz and clay) that accumulated as pressure solution and free-face dissolution removed the more soluble calcite when the rock was subjected to deviatoric stress. Cleavage domains are commonly wavy and, if closely spaced, anastamose with one another. In pure carbonate units that are not susceptible to cleavage development, the rock exhibits penetrative strain in the form of mechanical twins in calcite grains.

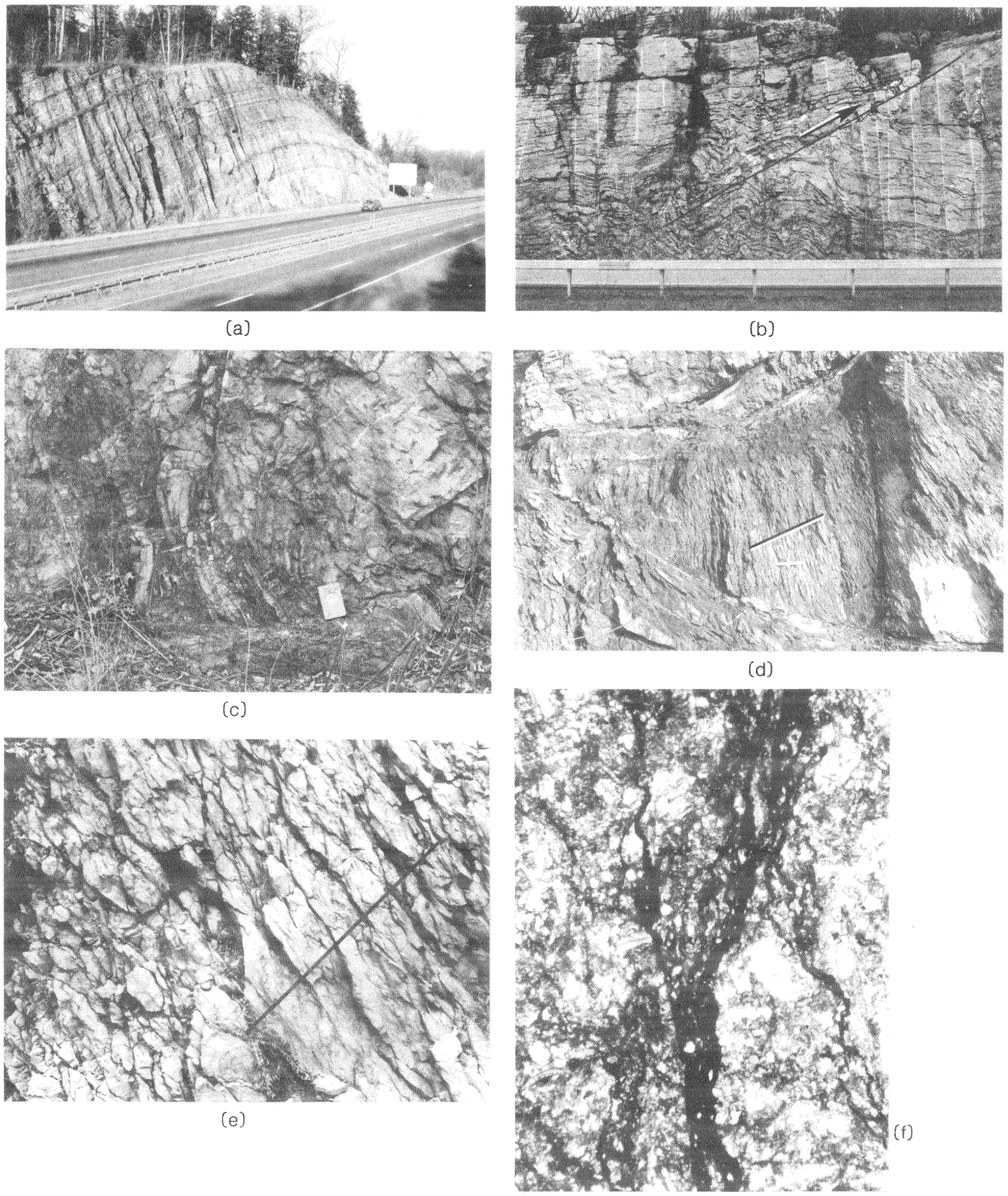


Figure 17: Photographs of folds and cleavage in the HVB. (a) First-order anticline involving Becraft through Port E Formations exposed along Route 199 north of Kingston. The light gray rock in the core of the fold is Becraft Limest (b) Mesoscopic folds in the Becraft Limestone adjacent to a backthrust (indicated by the heavy line and the arrov outcrop N3 along Route 23; (c) Asymmetric anticline above a horizontal fault in the New Scotland Formation at the end of Route 23 roadcut N2. The notebook rests on the fault plane. Note the thinning of the overturned limb of the (d) Cleavage in the Kalkberg Formation in the fault-bounded wedge on the northwest limb of the Central Anticlir outcrop N2. The long black/white line is parallel to bedding, cleavage is nearly vertical. The short white line is cm-long ruler; (e) Anastomosing wavy cleavage in the Schoharie Formation. The black line is parallel to bedc cleavage domains dip steeply to the east. Domains are spaced about 2-3 cm apart. Note bottle cap for scale Photomicrograph of a cleavage domain, defined by an accumulation of black clay. Note how the domain "horset toward its end by splitting into a number of thinner domains. Long dimension of photo is about 3 mm.

KINGSTON MAP AREA AND CROSS SECTIONS

The Appalachian Mountains are a sinuous range; the segment of the range in the United States has two recesses (bends that are concave toward the craton) separated by a salient (a bend that is convex toward the craton). The New York recess (Figure 2) marks the intersection of the New England Appalachians, which trend roughly north-south to N15°E, and the Pennsylvania salient, which trends northeast-southwest as it enters New York. The New York recess is defined both by the structural grain of the metamorphic hinterland and by the trends of folds and faults in the fold-thrust belt toward the foreland. The fold-thrust belt changes trend at two localities, the Delaware Water Gap and Kingston (Figure 2; Rodgers, 1970). Between the Delaware Water Gap and Kingston, structures trend northeast-southwest. North of Kingston, the structural trends are north-south to N15°E. The map of Plate 3 was produced in order to understand the nature of the change in structural trend at Kingston. Prior to the mapping, it was not clear whether the change in trend was a gradual change in structural trend from northeast-southwest to north-south or represented the interaction of two non-coaxial fold-thrust belts.

Based on the mapping shown in Plate 3, Marshak and others (1985) and Marshak and Tabor (1989) divided the fold-thrust belt in the Kingston area into three structural domains (Figures 18 and 19):

(1) *The northern domain*, extending from Lake Katrine, on the north, to Route 32 on the southeast, is characterized by fairly simple north-south-trending first-order folds. Few thrust faults are exposed. Shortening across this domain is on the order of 5%.

(2) *The southern domain*, extending southwest of a line that runs from the southern tip of Fly Mountain to Twin Lakes, is characterized by a northeast-southwest structural trend, a marked increase in the degree of shortening (shortening across the southern domain is about 30%), a westward propagation of detachment faults into the foreland (the fold-thrust belt extends much further to the west in the southern domain than it does in the northern domain), and by a probable progressive increase in the amount of shortening of Ordovician strata above the Austin Glen detachment.

(3) *The central domain* is the region between the southern end of Fly Mountain and the village of East Kingston. *Accommodation faulting* (faulting that accommodates the space problems in the core of a fold when the fold is overtightened) is abundant along the eastern margin of the domain. Along the western edge of the domain, the traces of two non-parallel spaced cleavages are visible locally on bedding surfaces, and there is a broad belt of north-plunging open low-amplitude folds. Horizontal slip lineations over-

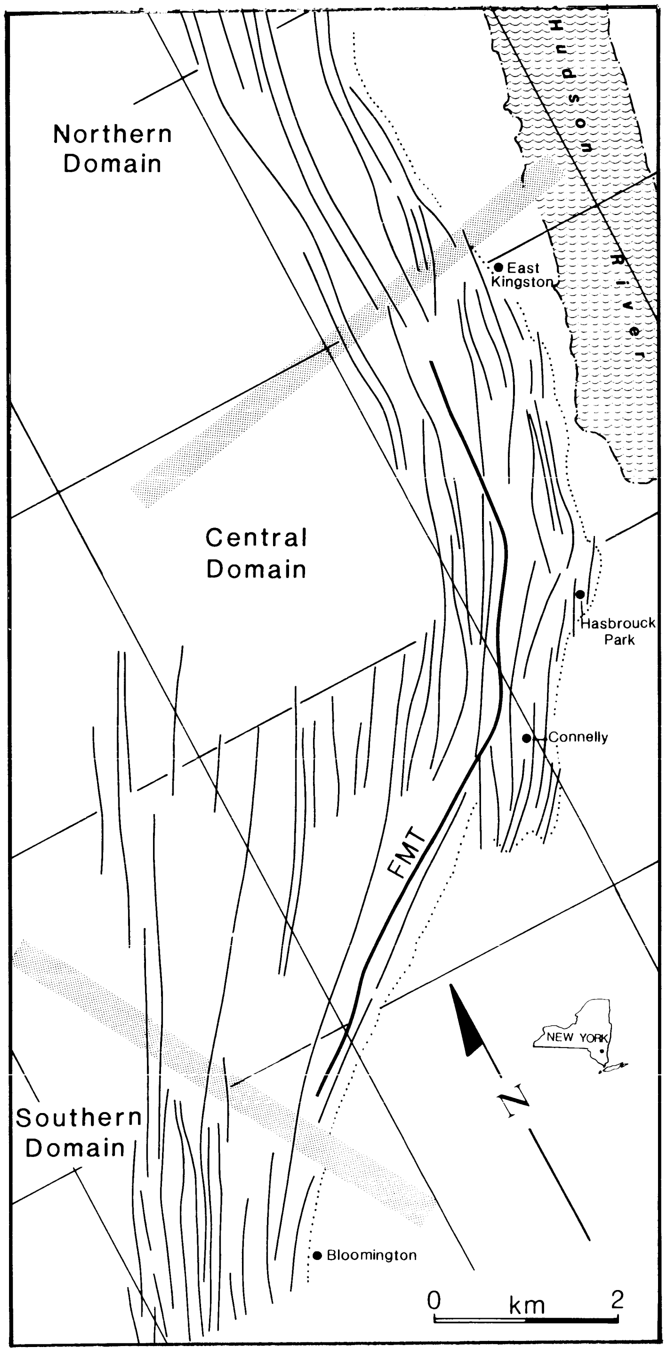


Figure 18: Sketch map of the Kingston region showing three structural domains (northern, central, and southern) and the traces of the principal faults and folds. This map was derived from the map in Plate 3 (after Marshak and Tabor, 1989). The thin dotted line is the trace of the Taconic unconformity. It can be used as a reference to identify localities on the map. Domain boundaries are indicated by stippled bands. FMT = Fly Mountain thrust. Straight rules are arbitrary north-south and east-west reference lines.

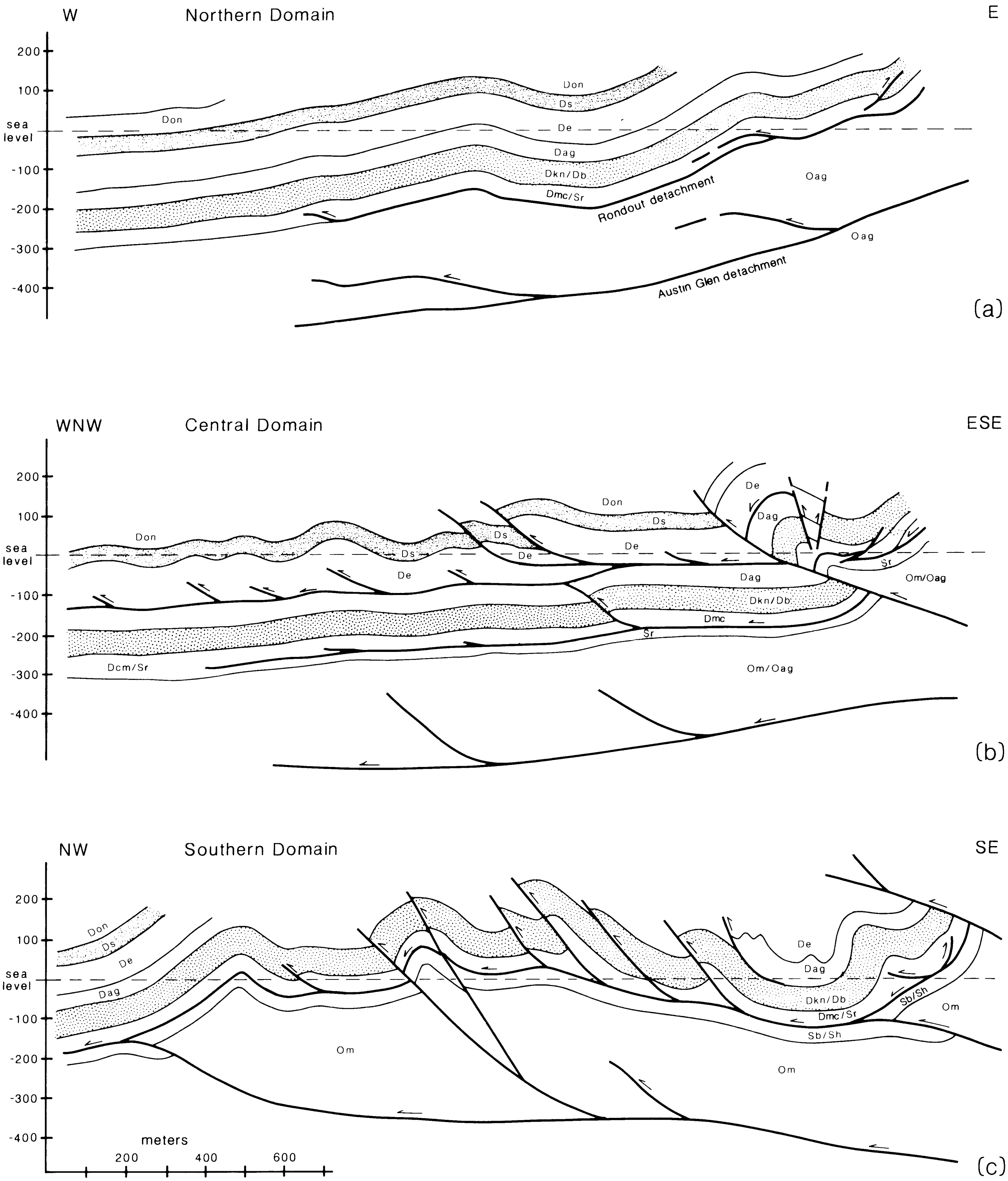


Figure 19: Cross-section models of the three structural domains of the Kingston region (from Marshak and Tabor, 1989). The lines of section and unit symbols are the same as those shown on Plate 3.

print down-dip slip lineations on bedding planes at many localities. Fold traces are bent in plan in the vicinity of Connelly. Large duplexes, numerous backthrusts, and reactivated faults occur all along the Helderberg escarpment where structural relations are more complex than elsewhere in the Kingston map area. At the southern end of Fly Mountain, Ordovician strata are thrust over the Silurian-Devonian sequence on the Fly Mountain thrust (Davis, 1883; Darton, 1894b; Tabor, 1985). The Fly Mountain thrust is a unique fault in that it cuts obliquely across structure and down section to the south. It appears to truncate folds in both the hanging wall and the footwall.

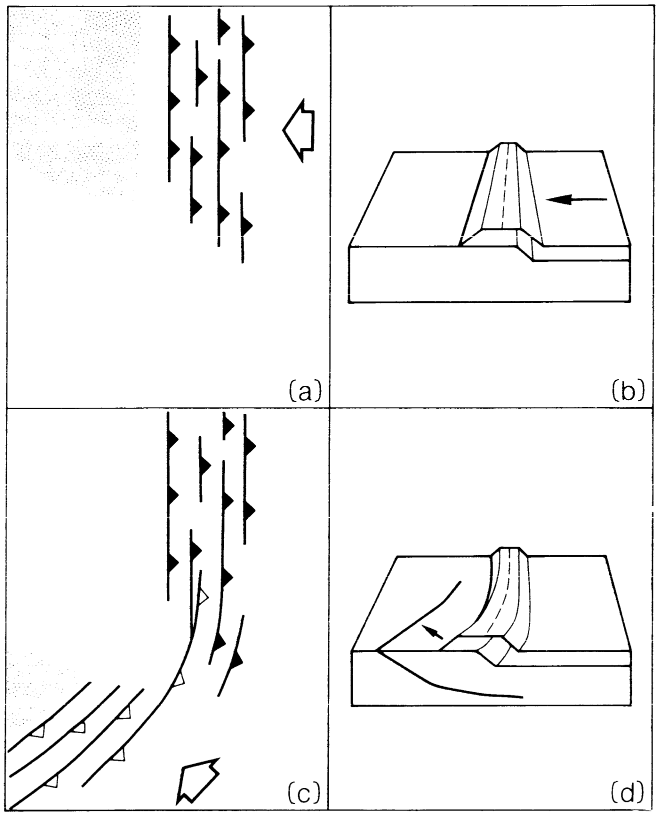


Figure 20: Interpretation of a two-stage evolution of the post-Taconic fold-thrust belt in the Kingston area (from Marshak and Tabor, 1989). (a) Map of stage 1, west-directed fold-thrust deformation. (b) Block diagram of a fault-bend fold developed during stage 1. (c) Map of stage 2 showing the overprint of a northwest-verging fold-thrust belt. (d) Block diagram showing the bending of a preexisting fold as it is carried in the hanging wall above a new fault.

Marshak and Tabor (1989) suggest that the occurrence of the three domains and the pattern of structure in the domains indicate that the bend at Kingston represents an overprint of two non-coaxial thrusting events; the northeast-southwest trend of the southern domain overprinted the north-south to N15°E (HVB) of the northern domain (Figure 20). The second thrusting event did not create interference domes and basins as is common in metamorphic terranes. Rather, as the structures of the central domain indicate, it reactivated thrust faults, developed accommodation structures, and refolded pre-existing folds; strike-slip lineations on bedding planes suggest that subsequent to the initial development of flexural-slip folds in the area, the folds were refolded around a vertical axis. The character of the Fly Mountain thrust is key to this proposal. Marshak and Tabor (1989) consider this fault to be out of sequence, in that it developed during the formation of the southern domain, cut across earlier-formed folds, and caused clockwise rotation of the earlier-formed folds carried in its hanging wall. It is important to note that the evidence for structural overprinting here is not clear cut, and other interpretations have been put forth (compare with Epstein and Lyttle, 1987).

If the change in trend of the fold-thrust structures at Kingston is an overprint, the area qualifies as an *intersection orocline*. An orocline is a bend in plan of the structural grain of an orogen caused by progressive change in the strike of segments of the orogen during its evolution. An intersection orocline is one in which the change in strike at the intersection of two non-parallel structural segments results from the younger segment overprinting the structures of the older segment and reorienting them in the region of overlap.

CONCLUSIONS AND TECTONIC INTERPRETATION

The maps of the HVB show that it has these key features: (1) The HVB extends continuously along the Hudson Valley from the Mohawk Valley on the north to Kingston on the south. Fold-thrust belt structures in Silurian-Devonian strata southwest of Kingston are similar in appearance to those north of Kingston but they are not parallel and possibly did not form during the same deformation event. Structures of the HVB can be traced westward along the Mohawk Valley as far west as Clarksville. At the latitude of Catskill, deformation dies out westwards because it is not apparent in rocks of the Catskill Mountains west of the Kiskatom Flats. Thus, the *pin line* (the boundary in plan view between the shortened region of the fold-thrust belt and the unshortened foreland) of the basal detachment of the HVB probably lies beneath the Kiskatom Flats. Outliers of HVB structures in Silurian-Devonian strata east of the Hudson River indicate that HVB deformation also involved the region east of the river.

(2) The HVB west of the Helderberg escarpment appears to be a two-tiered thrust system. Exposed thrust faults in the Silurian-Devonian sequence probably merge at depth with a

detachment in the Silurian Rondout Formation (the Rondout detachment) above the Taconic unconformity. The unconformity and the Rondout detachment are folded by large first-order folds, suggesting the presence of another detachment at depth, and this inferred detachment is called the Austin Glen detachment (Marshak, 1986a). The folding of the Rondout thrust system is a consequence of shortening above the Austin Glen detachment which may have been accomplished by development of detachment folds or by amplification of pre-existing folds in Ordovician rocks. During this shortening, the Silurian-Devonian sequence, a relatively rigid carbonate strut embedded between the ductile Austin Glen Formation and the ductile Bakoven shale, possibly buckled.

(3) There appears to be an orocline in the fold-thrust belt which is defined at Kingston by a change in structural grain from dominantly north-south trend to a dominantly northeast-southwest trend. This bend, which marks a significant structural discordance in the fold-thrust belt, represents the southern limit of the HVB. Southwest of the bend, Silurian-Devonian strata are involved in a fold-thrust belt that extends northwestward into the foreland and in which Ordovician strata are thrust over Silurian-Devonian strata. It is proposed that the orocline represents the overprint of the northeast-southwest-trending structures of the region southwest of Kingston on the pre-existing north-south structures of the HVB north of Kingston.

The relationship of the deformation events in the Silurian-Devonian units of the HVB to known deformational episodes in the Appalachian orogen has been debated for decades (see discussions by Woodward, 1957; Rodgers, 1967, 1970; Sanders, 1969; Murphy and others, 1980; Ratcliffe and others, 1975; Marshak, 1986a) and is still unclear. Two orogenic events might have led to HVB deformation: the Middle-Devonian Acadian orogeny (about 370 million years ago) and the Pennsylvanian/Permian Alleghenian orogeny (about 280 million years ago).

Controversy stems from the lack of stratigraphic evidence for the age of deformation. As described above, at the latitude of Catskill, HVB deformation is not visible west of the Kiskatom Flats and in rocks higher than the lower part of the Mount Marion Formation. Some authors (Murphy and others, 1980) have suggested that the age of the upper portion of the Mount Marion Formation delimits the age of HVB deformation, thus requiring the deformation to be pre-Middle Devonian: a result of the Acadian orogeny. However, because the regional dip is to the west, the apparent stratigraphic delimitation of deformation may only be a manifestation of the position of the pin line; i.e., the only reason that deformed younger rocks are not observed east of the Kiskatom Flats is that they have been removed by erosion. Under such an interpretation, deformation could be either Acadian or Alleghenian.

The author's preference, that the deformation is Acadian, is based on the location of the belt between an Acadian-age clastic wedge and an Acadian-age metamorphic belt. An Acadian-age fold-thrust belt would be expected in such a tectonic position. Extensive Alleghenian deformation at the latitude of Kingston has not been documented west of the Narraganset Bay region, located several hundred kilometers to the east. Unfortunately, radiometric ages necessary to date the HVB deformation are not available because datable non-detrital clay has not been isolated from cleavage domains. Recent work on fission-track and vitrinite analyses (e.g. Friedman, 1987) suggest that, at some point in their history, the rocks of the HVB were buried to depths of 7-8 kilometers; such burial could not have occurred before Pennsylvanian or Permian time. Unfortunately the age of maximum burial with respect to the age of deformation cannot be determined, but the occurrence of blocky spar at fault bends suggests that deformation occurred under relatively little overburden. Furthermore, it is possible that the evidence of elevated temperatures is not indicative of great burial depth, but rather of circulation of hot brines migrating from the orogen toward the craton.

As noted by Rodgers (1967), the age of deformation in the fold-thrust belt between Kingston and the Delaware Water Gap is also unclear. For various reasons, Epstein and Lyttle (1987) have argued that this segment of the belt is Alleghenian. If this proposal proves correct, then the Kingston orocline represents the intersection of Alleghenian structures on Acadian structures. Alternatively, if the HVB is an Alleghenian belt, then the Kingston orocline could represent the intersection of two non-coaxial phases of Alleghenian deformation (Geiser and Engelder, 1983). The answer to this tectonic dilemma awaits future studies.

FIELD GUIDE THROUGH THE HUDSON VALLEY FOLD-THRUST BELT (HVB)

This field guide provides directions to outcrops in the HVB between Catskill and Kingston that provided key data used in developing the hypotheses that the HVB is a two-tiered thrust system and that the bend in the trend of fold-thrust structures at Kingston is an orocline resulting from the interaction of two non-coaxial thrust systems. The contents of this guide are modified from Marshak (1986b) and Marshak and Geiser (1980). This guide also provides a roadlog to stops. The number in the left-hand column indicates the cumulative mileage measured (to the nearest tenth of a mile) from the start of the trip to the italicized landmark in the text; and the number in the right-hand column provides the mileage from the previous landmark. Stop localities are identified on Figures 21 and 22.

Note: *The purpose of this guide is only to provide directions to localities where key observations about the HVB were made during the development of the maps and charts provided. The presence of a stop description in this guide does not mean that the stop is necessarily safe; nor does it mean that it is necessarily legal to visit the stop without permission. Some of the stops are dangerous because of traffic or because of the possibility of falling rock. Field trip leaders should exercise their judgement as to whether a stop is logistically feasible or is sufficiently safe for the group of visitors they are guiding. It is recommended that participants wear hard hats at all high-wall outcrops. Many of the stops are on private land. Trip leaders must determine if permission is necessary to visit an outcrop and must obtain the appropriate permission. Permission is required to enter most quarries. The author of this guide and the New York State Museum do not assume responsibility for the safety of field trip participants who use this roadlog.*

Cum. Miles	Miles	
0.0	0.0	**Start of Log:** The roadlog mileage begins at New York State Thruway Exit 21 *tollgate* at Catskill. Proceed through the tollgate and drive down the access road to its junction with Route 23B. The outcrop at the tollgate is composed of the lower part of the New Scotland Formation and is very fossiliferous; bedding planes are covered with well preserved brachiopods.
0.2	0.2	*Junction* between Route 23B and the tollgate access road. Turn left (southeast), toward the Rip Van Winkle Bridge. Proceed southeast on Route 23B for 0.3 miles. Park on the shoulder just before the entrance ramp from Route 23B onto Route 23. The large roadcuts along Route 23 constitute Stops 1 and 2.
		Stop 1 includes the Route 23 roadcuts east of the Thruway which are numbered on Plate 1 as N3-N5 and S3. The stop is divided into parts A, B, and C.
0.5	0.3	To reach Stop 1A, leave vehicles parked on the *shoulder of Route 23B*, just north of the ramp leading to 23, cross Route 23B (watch for traffic ! !), and walk east up the exit ramp that leads from Route 23 (westbound) down to Route 23B. Stop 1A is the roadcut (roadcut N5 of Plate 1) at the top of the ramp.

Stop 1A: (Roadcut N5 along exit ramp from Route 23 to Route 23B.) This is a classic exposure of the Taconic unconformity (see photograph in Rodgers, 1971 and Marshak, 1986a). In this outcrop, we see west-dipping beds of the Rondout through Kalkberg Formations in angular discordance above steeply-dipping beds of the Austin Glen Formation. This unconformity represents a hiatus of about 50-70 million years. Ordovician beds are bent slightly just below the unconformity and there are slip lineations on the unconformity. These features suggest that movement occurred on the unconformity but give no indication of the magnitude of movement. The sense of shear is compatible with the association of the movement on the unconformity with flexural slip during the development of the Tollgate syncline (a first-order fold of the HVB). The top meter of the Rondout at roadcut N5 is strongly deformed. Mesoscopic folds in this interval indicate a downdip (*i.e.*, west-northwest verging) sense of slip (Figure 15c) which is opposite to what would be expected for slip associated with flexural movement at this locality. Thus, movement in the upper Rondout is probably a consequence of west-directed transport on a detachment fault (Figure 13a). This fault was called the "Rondout detachment" by Marshak (1986a).

In roadcut N5, the Rondout is overlain by homoclinally-dipping beds of the Manlius, Coeymans, and Kalkberg Formations. In this sequence, there are numerous bedding-plane slip surfaces covered with calcite slip fibers (Figure 15b). The presence of these slip fibers indicates that movement on the surfaces did not occur by frictional sliding, but rather by crack-seal incremental fiber growth (Ramsay, 1980); each increment of extension was nearly parallel to the fracture (fault) surface. The long axis of a fiber is parallel to the transport vector, and the imbrication of sheets of fibers gives the sense of slip. Incipient cleavage is visible in the Kalkberg Formation but not in the Coeymans or Manlius Formations.

Looking west toward Route 23B, it is apparent that outcrop N5 is on the east limb of a

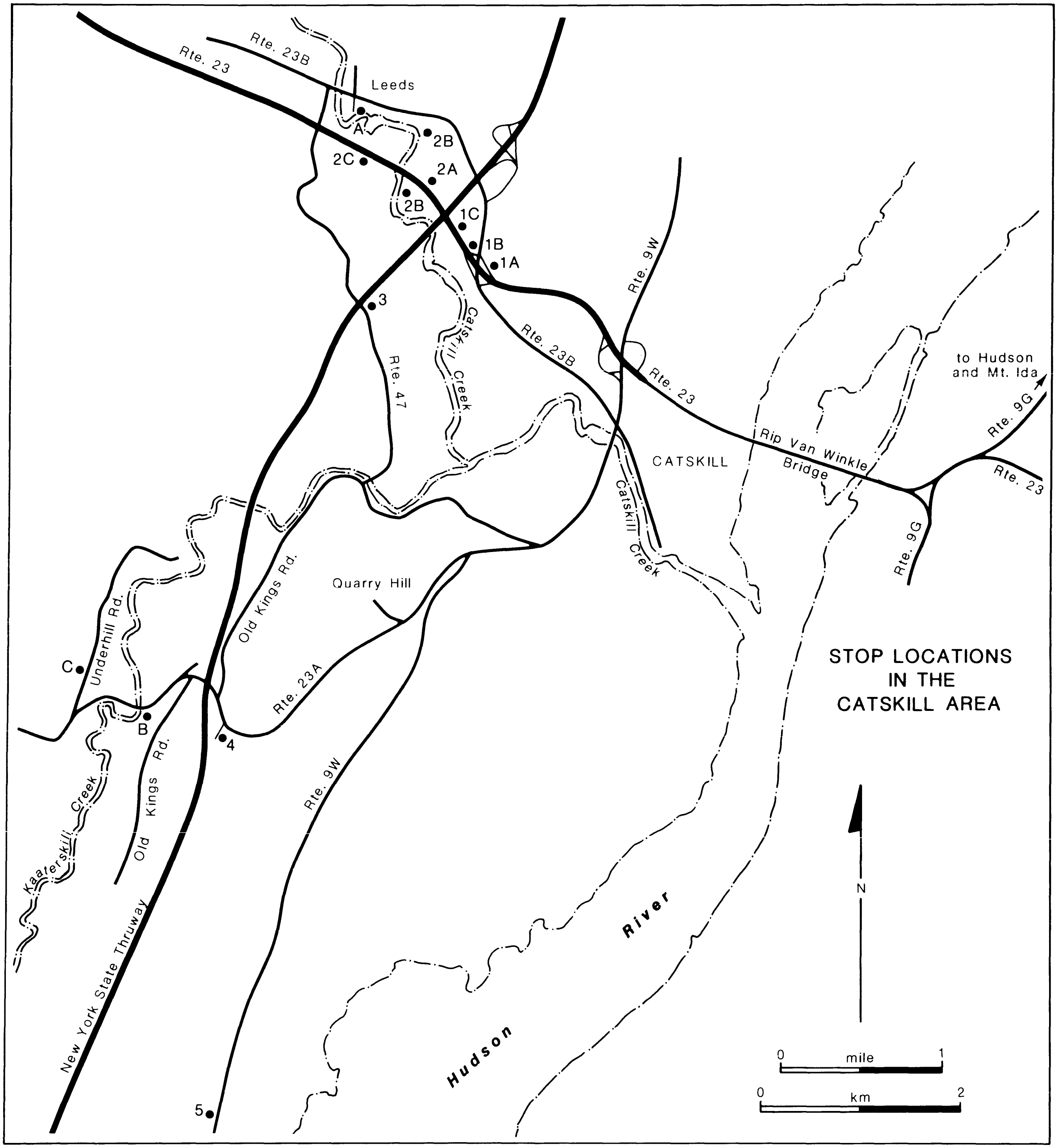


Figure 21: Map showing location of stops in the Catskill area that are described in the field guide. Positions of stops (numbers) and optional stops (letters) are indicated by black dots.

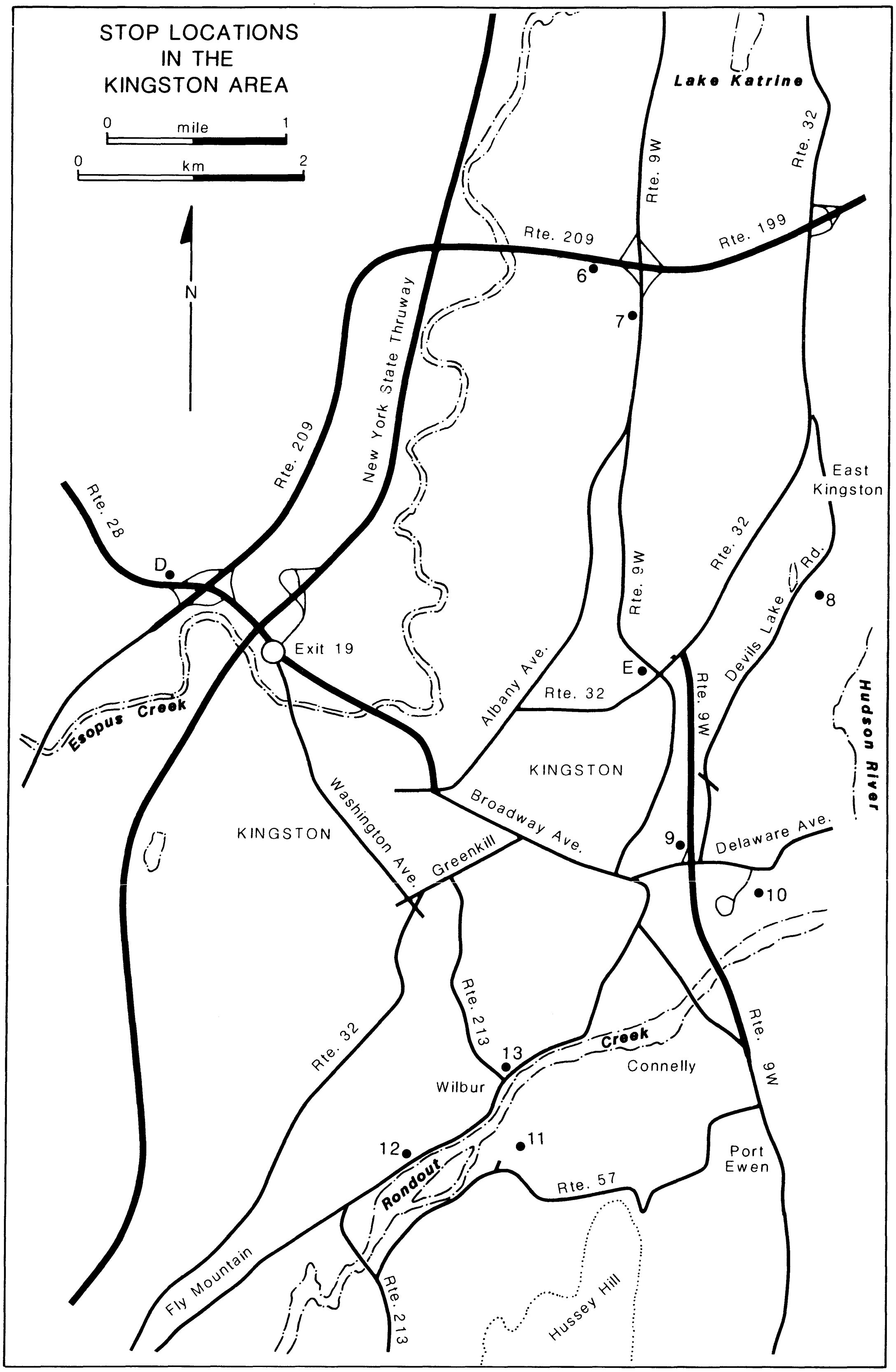


Figure 22: Map showing location of stops in Kingston area that are described in the field guide. Positions of stops (numbers) and optional stops (letters) are indicated by black dots.

Cum. Miles | Miles

broad syncline. This syncline, the Tollgate syncline, is characteristic of the first-order open conical folds of the HVB. In the core of this large fold, there are low-amplitude flexures.

Walk back toward vehicles and recross Route 23B.

The outcrop along the west edge of Route 23B just north of Route 23 is composed of the Kalkberg Formation. Notice that there are numerous small west-verging thrust faults exposed in this outcrop that result in tectonic thickening of the Kalkberg on the west limb of the Tollgate syncline. Beds directly beneath these faults have been "dragged" over by movement on the faults to create tight mesoscopic folds.

Walk up the entrance ramp from 23B to 23 westbound.

Stop 1B: (Entrance ramp to Route 23 from 23B, roadcut N4.) This roadcut contains two excellent examples of thrust faults. The lower fault (further west) places the Manlius Formation over the Kalkberg Formation (Figure 15d), whereas the upper fault repeats a portion of the Coeymans Limestone. The lower fault plane is marked by the occurrence of breccia and of blocky calcite spar and thus displays typical surface characteristics of cross-strata faults in the HVB. The faults in roadcut N4 may be out-of-the-syncline faults. The covered floor of the small valley just west of this outcrop is the core of the Eastern anticline and is underlain by Austin Glen Formation. The scarp on the east side of this valley contains examples of lateral ramps (faults which cut upsection along strike). **End.**

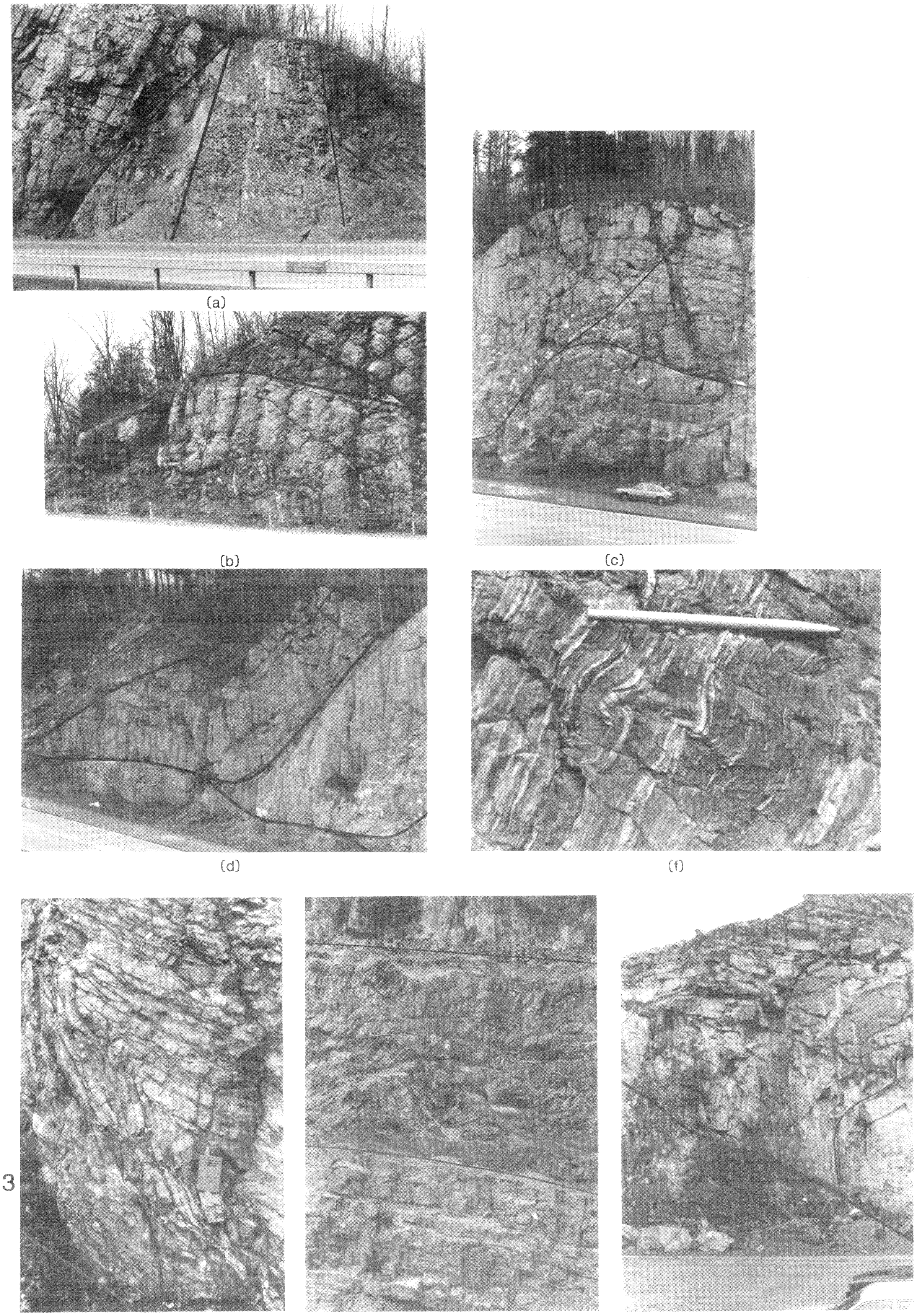
Continue walking northwest along Route 23. The large roadcuts that border Route 23 in the interval immediately east of the Thruway are N3 and S3, which together constitute Stop 1C.

Stop 1C: This stop consists of roadcuts N3 and S3, which span the remainder of the interval between Route 23B and the Route 23 bridge over the Thruway. At the east end of these outcrops, there is another exposure of the Taconic unconformity (Figure 23a). Above the unconformity, the Rondout is thicker than it is in outcrop N5. This thickening appears to be a tectonic feature; the structure of the Rondout outcrop at this locality is very complex. In outcrop N3, note, in particular, the nearly circular fold at the base of the outcrop, and the large number of prominent faults in the Rondout-Manlius contact area. In outcrop S3, note how thrusting has resulted in emplacement of a tongue-shaped wedge of Rondout over Manlius (Figure 23b). The Rondout and Manlius Formations have also been tightly folded. The geometry of the Rondout/Manlius contact changes significantly in the interval between N3 and S3.

Continuing west along N3, the roadcut exposes a homoclinal-dipping interval of Helderberg Group rocks with gradually decreasing dips. Note the fiber-coated slip surfaces on many of the bedding planes. Mutual cross-cutting relations between the fibers and the cleavage domains can be recognized and indicate that cleavage developed throughout the formation of the folds and faults. In the Kalkberg Formation, there are examples of shear zones in which a fiber-coated slip surface is bounded by a 20 cm-thick band of intensely cleaved rock with the cleavage at low angles to bedding (Figure 15f).

In the Becraft Limestone of N3, there is an excellent example of a "backthrust;" movement on this fault resulted in transport of hanging-wall strata to the east (Figure 17b). There are also two examples of "incipient" backthrusts. These incipient faults are represented by zones of *en echelon* extension gashes and of mesoscopic folding. Comparison of N3 with S3 indicates that the backthrust trace is oblique to the strike of the fold-thrust belt. Finally, note the occurrence of cleavage in the shale beds of the lower part of the Becraft Formation. The inclination of cleavage in these beds indicates the westward sense of shear between beds. Calcite grains in the grainstone beds display twinning strains of up to 7% (Marshak and Engelder, 1985). Note that the Thruway follows the hinge trace of the Thruway syncline. **End.**

0.7 | 0.2 | Drivers should turn right off 23B, proceed up the entrance ramp, and drive a short distance northwest down Route 23. Drivers can pick up passengers on the shoulder of Route 23, just east of the *bridge over the Thruway*, or can



(a) (b) (c) (d) (f) (e) (g) (h)

Figure 23

Cum. Miles	Miles	
		continue to the far side of Stop 2 and wait for passengers at the Catskill Creek bridge. Proceed northwest (either in vehicles or on foot) across the bridge over the Thruway.
		Stop 2 consists of the roadcuts (N2 and S2) between the Thruway and the Route 23 bridge over Catskill Creek, the roadcuts (N1 and S1) west of the bridge, and the stream cuts along Catskill Creek upstream and downstream of the Route 23 bridge.
1.0	0.3	**Stop 2A:** This stop consists of roadcuts N2 and S2 on Route 23 (Plate 1). Outcrop N2 displays beautiful examples of folded detachment faults, ramp to flat thrust geometries, cleavage distributions controlled by structural setting, tectonic thickening and thinning, and horse geometry. The description is written with the assumption that the visitor walks from the *southeast end of outcrop N2* toward the northwest.

At the southeast end of N2, the New Scotland Formation forms the visible part of the Rip van Winkle anticline. This fold is asymmetric and verges toward the west. Adjacent to the northwest is the Town and Country syncline, whose core is cut by faults. At the east edge of this syncline, beds of the Becraft Limestone were folded so tightly that inner-arc beds detached from outer arc beds, and a small lozenge of shale was squeezed into the resulting void. At this locality, fibrous veins accommodated extension of the Becraft beds. In profile, these veins taper downward toward the inner arc of folds.

Notice that the Rip Van Winkle anticline overlies a thrust fault in outcrop S2 but does not overlie a thrust fault in outcrop N2. The fault at the base of the Rip Van Winkle anticline appears to die out in the interval of the highway, so the Rip van Winkle anticline extends to the north of the fault trace. This relationship suggests that the anticline developed in advance of the development of a throughgoing fault and that the anticline is a fault-propagation fold.

Other contrasts in structural geometry distinguish the east end of S2 from the east end of N2. These contrasts result, in part, from movement on out-of-the-syncline faults in the core of the Town and Country syncline. These faults, which trend obliquely to the strike of the fold, bound a small V-shaped (in cross section) pop-up or horst, which was squeezed up and out of the core of the syncline.

Continuing northwest along N2, we proceed downsection across the New Scotland-Kalkberg formational contact, through an interval of Kalkberg beds contorted by mesoscopic folding and faulting (which is also visible in S2), into an interval of homoclinal Kalkberg. The sheet of contorted Kalkberg is bounded both above and below by homoclinal beds and is separated from these beds by detachment horizons.

The core of the Central anticline lies 20 m further to the west of the Kalkberg/New Scotland contact. This fold is structurally the most interesting fold of the HVB near Catskill. Manlius and Coeymans are found in the core of the fold in both N2 and S2. On the east limb of the fold in N2, a detachment flat follows bedding just above the Manlius-Coeymans contact. At the crest of the fold, this fault becomes a ramp that cuts upsection through the Coeymans; there is a wedge of calcite spar at the junction between the flat and the hangingwall ramp (Figure 23c). A northwest-dipping

Figure 23: Photographs of representative structures visible at field stops. (a) The Rondout detachment and the Taconic unconformity at the east end of Route 23 roadcut N3. The unconformity is indicated by the longer thin black line. The shorter thin line parallels bedding in the Ordovician strata. Thrust faults (folded so that they now dip west) are indicated by the heavy lines. Vergence on the faults is to the west. The arrow points to a "circular fold." (b) The wedge of Rondout inserted between layers of the Manlius Formation in Route 23 roadcut S3 is outlined. Note the fold beneath the wedge. (c) The Central anticline. The black lines indicate the thrust that ramps across the Coeymans Limestone, then bends into bedding and goes down the west limb of the fold, and the backthrust that rises from the crest of the fold. (d) The folded horses on the northwest limb of the Central anticline of roadcut N2 are outlined. The upper horse contains the mesoscopic folds of the Kalkberg; the western tip of the lower horse is the "fault-bounded wedge." (e) A chevron fold in the Kalkberg, from the region shown in part d; (f) Microfolds in the upper Esopus Shale in roadcut N3; (g) The Esopus detachment just above the Esopus/Glenerie contact along Route 23A, just east of the Thruway. Note the folds in the basal Esopus. Notebook for scale; (h) The Prien thrust in the quarry near Cementon.

Cum. Miles	Miles	
		backthrust cuts steeply across the Coeymans/Kalkberg contact at the crest of the anticline (Figure 23c).

Just to the west of the fold crest, the fault returns into bedding near the top of the Coeymans and continues down the west limb almost to the base of the outcrop, where it bends and merges with another ramp that rises from the subsurface. There is a thick wedge of calcite spar at the fault bend, the occurrence of which suggests that a void opened along the fault bend during movement on the fault. The fault can be traced westward as a subhorizontal surface that cuts upsection across the northwest-dipping strata of the Kalkberg Formation. Erosion has removed the rock below this fault, so the fault lies at the base of an overhang. Progressing westward into the west limb of the Central Anticline, we see a fault-bounded contorted horse of Kalkberg (Figure 23d), in which the Kalkberg beds are folded into tight chevron folds (Figure 23e).

The wedge of Kalkberg that lies beneath the contorted sheet and above the horizontal fault has a very strong spaced cleavage (Figures 23d; 17d). This cleavage intensifies and is reoriented close to the fault. Note also that there is significant extension parallel with cleavage in the wedge and that the tip of the wedge is brecciated. Cleavage development intensifies toward the tip of the wedge. Cleavage does not occur in the underlying Manlius and Coeymans, but these carbonate-rich units do contain a stockwork array of veins.

This locality demonstrates that cleavage distribution is controlled both by lithology and by strain; cleavage forms only in limestone containing 10% or more argillaceous material. Penetrative strain in limestone with less than 10% argillaceous material is accommodated by formation of mechanical twins in the calcite grains. Cleavage-domain spacing decreases as strain increases. The relations at this locality may also suggest that part of the rock that dissolved during creation of the cleavage was reprecipitated locally to create the cleavage-parallel extension and part may be transferred to veins in adjacent units or along faults.

A detachment fault lies at the base of the New Scotland Formation in N2 (Figure 23d), and there are three or four apparent detachment horizons within the New Scotland. A near-horizontal ramp cuts across the New Scotland near the base of the west end of the outcrop. There are several localities along this ramp where beds of the hanging wall are dragged into small overturned asymmetric folds. The overturned limbs of these folds are thinned probably by formation of late-stage bedding-parallel cleavage.

The Becraft Limestone is present just to the northwest of the N2 outcrop near the bridge; this unit steepens to near vertical beneath the bridge. *Aspidocrinus* holdfasts are visible on Becraft bedding planes beneath the bridge.

Outcrop S2 also displays the Central anticline, but the internal geometry of the fold is quite different from that visible in N2 (Figure 16b). A major ramp [fault segment 1 in Figure 16] emplaces the Manlius through Kalkberg over Kalkberg and New Scotland. This ramp splays into two faults [fault segments 2 and 3] which bound a horse of New Scotland. The horse is internally folded.

The contrast between N2 and S2 suggests that the space now occupied by the highway once contained a lateral ramp; the flat at the base and in the core of the Central anticline of S2 [fault segment 1] appears to split into two splays to the north. The lower splay [fault segment 4] is the ramp that arises from the subsurface at the base of the anticline in N2; the upper splay [fault segment 5] ramps upsection to the north and becomes the fault at the base of the Coeymans on the southeast limb of the Central anticline in N2. **End.**

Cum. Miles	Miles	
1.2	0.2	Drivers should proceed to the *east side of the bridge over Catskill Creek* and wait for passengers.

Stop 2B: (Creek bed exposures) Pathways starting at either side of the bridge over Catskill Creek provide access to the excellent exposures that occur along the banks of the creek. Permission from landowners is required.

A complete exposure of the Mill Falls anticline, involving the Glenerie Formation through Onondaga Limestone, is present upstream of the bridge just below the Mill Falls.

Cum. Miles	Miles	
		Thrust faults occur in the core of the fold. This exposure also displays a cleavage fan in the Esopus Shale (Figure 11d). At the right-angle bend in the creek, upstream of the bridge, there is an exposure of the Creek Bend syncline. A traverse downstream from the bridge first encounters vertical to overturned strata of the Becraft Limestone and Alsen Formation that form a waterfall, then horses of the duplex that forms the core of the Central anticline exposed through structural windows. Below the bend where the creek begins to flow east, there is a thrust fault which emplaces New Scotland over Becraft. In this area, as displayed on the map of Plate 2, the lower part of the New Scotland Formation is repeated three times. **End.**
		Return to the vehicles and proceed northwest on Route 23, across Catskill Creek.
1.5	0.3	**Stop 2C:** *Roadcuts N1 and S1* expose the Esopus through Onondaga Formations in the Mill Falls anticline (Figure 11e). A cleavage fan is visible in the Esopus of the core of the fold. The upper 2 m of the Esopus is composed of thin interlayers of shale and siltstone which are crinkled into tiny folds (Figure 23f). Note the thick veins that rise upwards from a shear horizon at the top of the Schoharie Formation in S1. Some of the veins at this locality contain both calcite and quartz. Also in S1, note the horizontal ramp at the top of the outcrop along which the Schoharie moved to the west. The youngest unit that occurs in these outcrops is the Onondaga.
1.8	0.3	Return to vehicles and proceed to *intersection of 23 with Cauterskill Road.* A Dairy Queen is on the southwest corner, and a gas station is on the northwest corner. The lowland is underlain by Bakoven Shale (covered by glacial deposits) and the high escarpment to the west is the Hooge Berg, which is underlain by Mount Marion Formation.

Directions to **Optional Stop A**

0.0	0.0	*Junction of 23 with Cauterskill Road.*
0.3	0.3	Turn right (north) on Cauterskill Road and proceed to the *intersection of Cauterskill Road with 23B.* Turn right and cross the old stone Leeds Bridge into the village of Leeds.
0.5	0.2	Turn right off of 23B onto *Gilfeather Park Road* (a small lane). This lane intersects 23B across from the Mohican Trading Post store and is just west of O'Briens Bar.
0.6	0.1	Proceed down the lane to the *turnaround.* Park at the turnaround and walk down to the bank of Catskill Creek.

Cum. Miles	Miles	
		Stop A: At this vantage point, you are standing on the Onondaga Limestone near the crest of the westernmost anticline (the Leeds anticline, named by Babcock, 1966) of the HVB. To the west of this locality, beds dip homoclinally westward. The Schoharie Formation is exposed downstream, at the waterfall, and the beds steepen and dip into the Mill Pond; note that the eastern limb of the Leeds anticline is steeper than the west limb. The pond lies in the Mill Pond syncline. At the east edge of the pond are vertical to overturned beds of uppermost Schoharie; a bedding plane forms the large vertical wall at the southeast corner of the pond.
1.1	0.5	Return to vehicles and retrace route back to the *junction of Cauterskill Road with Route 23* (near the Dairy Queen). **End.**

1.8	0.0	Mileage starts at *junction of Cauterskill Road with Route 23,* as if Optional Stop A had not been taken. Turn left off Route 23 onto Cauterskill Road, and proceed south. Cauterskill Road is also called County Road 47.
2.3	0.5	*Junction of Cauterskill Road with Vedder Mountain Road.* Continue straight on Cauterskill Road.
3.1	0.8	*Bridge over New York State Thruway.* Cross the bridge and park on the shoulder immediately to the east of the bridge.
3.2	0.1	**Stop 3:** This is a *roadcut outcrop* of Schoharie Formation at the bridge taking Cauterskill Road over the Thruway. The Esopus Shale is visible at the east end of the outcrop. The principal feature of interest at this locality is the anastomosing spaced cleavage in the Schoharie (Figure 17). The cleavage is the dominant fabric of the outcrop and dips steeply toward the east. Bedding is recognized by subtle buff-to-tan color banding

Cum. Miles	Miles	
		which dips toward the west. Notice the selvages, composed dominantly of clay, that define the cleavage domains, and notice how domains tend to terminate along their trace as horsetails. Cleavage in the adjacent Esopus is much more closely spaced. The contrast in cleavage spacing between the Esopus and Schoharie is another example of the control that lithology has on cleavage development (Marshak and Engelder, 1985). **End.**
		Board vehicles and continue southeast on Cauterskill Road.
4.3	1.1	*Steel-deck bridge over Kaaterskill Creek.* The rocks at the waterfall just downstream of the bridge are Ordovician Austin Glen Formation.
4.4	0.1	*T-junction.* Turn right and head in the upstream direction on Green County Route 47 (Old Kings Road). Do not recross creek.
6.2	1.8	*Fork in the road,* just before highway department garage. Bear to the left (southeast), and follow the roadcut outcrop of Onondaga Limestone.
6.5	0.3	*Junction of County Road 47 with Route 23A.* At this point, turn right to Optional Stops B and C, or turn left to Stop 4.

Directions to **Optional Stops B and C**

0.0	0.0	*Junction of County Road 47 with Route 23A.* Turn sharp right and head northwest on Route 23A.
0.1	0.1	*Bridge over the New York State Thruway.* Outcrop at the west end of the bridge is Schoharie Formation.
0.2	0.1	*Junction of Route 23A with Old Kings Road.* Pull off onto the right (north side of 23A) and park at the intersection. The outcrops on the south side of 23A display an asymmetric anticline composed of Onondaga Limestone; the west limb dips very steeply. Walk 0.3 miles down the hill to the Route 23A bridge over Cauterskill Creek (there's no parking at the bridge).
0.5	0.3	**Stop B:** *Bridge over Cauterskill Creek.* The contact between the Onondaga Limestone and the Bakoven Shale is in the creek just downstream of the bridge (Figure 11f). This contact represents the initiation of the siliciclastic deposition that grades upward into the coarser units of the Catskill clastic wedge. Note the numerous small shear zones and the mesoscopic folding in the soft shale. The Bakoven Shale is a candidate for the weak interval in which thrusting of the HVB propagates westward to the pin line.
		Return to the vehicles. Proceed west (toward the Catskill Mountains) on Route 23A. **End.**
0.5	0.3	Drive downhill to the *bridge over Cauterskill Creek* (Stop B). Cross bridge and continue uphill on Route 23A.
1.0	0.5	*Junction with Underhill Road.* Turn right onto Underhill Road.
1.3	0.3	**Stop C:** Drive north on Underhill Road for 1/3 mile, then pull off on the right and park. Outcrop on the north side of the road is *Mount Marion Formation.* Walk to the north end of the outcrop and look back south at the outcrop. From this vantage point a well-developed spaced cleavage is visible in the lower two-thirds of the outcrop. This outcrop is pictured in the 1980 Geological Society of America Bulletin article by Murphy, Bruno, and Lanney. They suggested that the boundary between cleaved and uncleaved rock in this outcrop provided a stratigraphic constraint on the age of deformation in the fold-thrust belt. Marshak (1983, 1986a) suggested that the lack of cleavage in the upper beds of the outcrop is merely a reflection of lithologic control on cleavage development. In fact, a weak cleavage may be present in the upper third of the outcrop. **End.**
		Return to vehicles, drive a short distance down Underhill Road and make a U-turn. Return to junction with 23A.
1.9	0.6	*Junction of Underhill Road with 23A.* Turn left and retrace route on 23A (proceed east).
2.3	0.4	*Bridge over Cauterskill Creek.*
2.8	0.5	*Bridge over New York State Thruway.*
3.4	0.6	*Junction* of 23A with County Road 47.

6.5	0.0	Mileage restarts at *Junction of 23A and County Road 47,* as if Stops B and C were not made.

Cum. Miles	Miles	
		Turn left onto 23A and proceed 0.1 mile to the large roadcut along the abandoned Thruway ramp on the right. Pull off onto the ramp on the right.
6.6	0.1	**Stop 4:** *Roadcut in Glenerie and Esopus Formations* (the "Esopus Detachment"). This cut exposes disharmonic folds that have formed in association with movement on a detachment fault between the Esopus and Glenerie Formations (Figure 23g). This outcrop inspires considerable debate about the origin of the deformation. Is the structure tectonic, or is it a consequence of slumping that was penecontemporaneous with deposition? The association of fractures, cleavages, and shear zones with the folds indicates that the deformation is tectonic. Deformation occurred at this horizon because of the major contrast in ductility between the Esopus and Glenerie. The lowermost Esopus is composed of alternating beds of siltstone and shale, and such a sequence is susceptible to formation of mesoscopic folds. The overlying Esopus is more homogeneous and contains closely spaced to slaty cleavage. The detachment at the contact may reflect differential shortening between the Esopus and Glenerie. **End.**
		Board vehicles, turn right off of the abandoned ramp, and continue southeast on Route 23A, toward the town of Catskill. This route runs along the outcrop belt of the Alsen and Port Ewen Formations.
8.2	1.6	On the left (north) side of Route 23A is a *large roadcut* of Helderberg Group rocks. Adjacent to the east is a small abandoned quarry that is now occupied by large steel gas tanks. The road leading to "Quarry Hill" (a large active quarry exposing a large syncline and other interesting structures) begins at the east end of this small abandoned quarry.
8.7	0.5	*Junction of Route 9W with 23A.* Turn right at the blinking light and proceed south on Route 9W. Route 9W follows the base of the Helderberg Escarpment. The escarpment is an erosional feature; its base coincides with the Taconic unconformity at many localities, and its face is composed of the Rondout Formation and the Helderberg Group.
9.4	0.7	*Exposure* of Austin Glen Formation.

Cum. Miles	Miles	
9.7	0.3	Large *junkyard* on the left (east), with Hudson River visible in the distance. The Great Vly (Dutch word), a broad valley, lies on the far side of the ridge to the west of 9W. The Great Vly is a mirror image of the Fuyk Valley to the north (Quarry Hill lies to the east of the Fuyk Valley). Both the Great Vly and the Fuyk Valley represent the eroded cores of plunging anticlines; the Vly anticline plunges north and the Fuyk anticline plunges south (Figure 8b).
11.9	2.2	*Entrance to Independent Cement Corporation quarry* on the right.
12.5	0.6	*Entrance to Independent Cement Corporation plant.* (Permission to enter quarries can be obtained from the plant office).
13.0	0.5	Cross under *conveyer belt*.
13.2	0.2	**Stop 5:** *Entrance to the Lehigh Cement quarry.* In order to make it possible for visitors to locate the outcrops discussed, the mileage log starts at the entrance of the quarry. The geology at Stop 5 was described by Zadins (1983), and the text for this stop was adapted from a description by Zadins (*in* Marshak, 1986b). Local geology has also been described by Leftwich (1973).

0.0	0.0	*Entrance to Lehigh Cement quarry.* (There is a parking area across the road from this entrance.)
0.1	0.1	Drive uphill, turn right (west) past the *abandoned crusher building.* The New Scotland Formation dips steeply west here.
0.2	0.1	*Outcrop* to the left (south wall) contains an angular kink fold in the upper part of the New Scotland Formation.
0.3	0.1	*"Danger, Drive Slowly" sign* on the right (north side of the roadway). Stop at this sign and leave the vehicles. This exposure of the Prien thrust exhibits a variety of thrust structures (Figure 23h; Figure 24a). The Prien thrust is a blind thrust on which there has been approximately 16 m of stratigraphic throw. This fault places a hanging-wall of vertical beds of the Alsen and Port Ewen Formations onto a footwall of east-dipping beds of the lower Glenerie Formation. Cutoff angles were modified by small-scale thrust

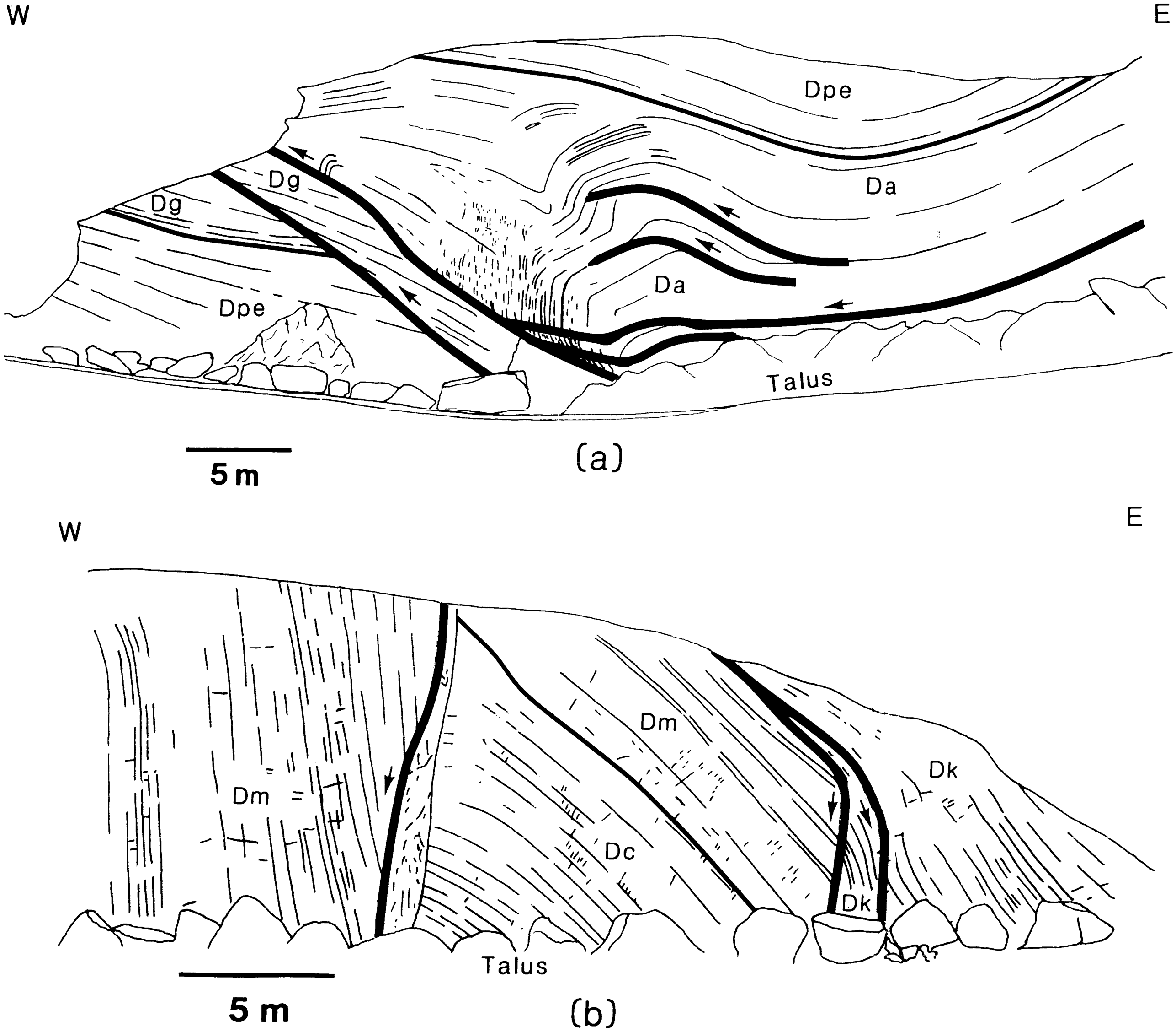


Figure 24: Outcrop sketches of structures in the quarry near Cementon (modified from Zadins, 1983, in Marshak, 1986b). Cleavage traces are indicated by short line segments, bedding traces by longer line segments, and faults by heavy black lines. (a) Prien thrust, near the quarry entrance. Note the cleavage in the forelimb of the anticline. Da = Alsen, Dpe = Port Ewen, Dg = Glenerie. (b) Thrusts showing hanging wall and footwall cutoffs in the cut adjacent to the conveyer belt. Dm = Manlius, Dc = Coeymans, Dk = Kalkberg.

Cum. Miles	Miles	
		imbrication at high angles to bedding in the fore-limb of the ramp anticline. Two minor thrust faults truncate the vertical fore-limb of the anticline. A steeply-dipping spaced cleavage (N20°E strike) parallels bedding in the vertical forelimb. Cleavage domains undergo a decrease in spacing and refract towards the thrust contact. The hanging-wall west of the ramp anticline contains a synformal kink fold; cleavage is intensified in the core of this fold. Further west (not visible in the figure), the structure is dominated by a stack of imbricate thrusts which are exposed on the ridges that remain after the quarry operation.
		Return to vehicles and continue west.
0.4	0.1	*Exposure of the Lisa thrust* occurs on the right (north wall). Movement on this thrust resulted in the emplacement of Becraft Limestone over the Glenerie Formation. Proceed west.
0.5	0.1	*Exposure of the Victoria thrust.* This fault also emplaces Becraft Limestone on Glenerie For-

Cum. Miles	Miles	
		mation. A duplex containing numerous horses of Glenerie Formation extends to the top of the outcrop along this thrust. This exposure is well worth a stop.
0.6	0.1	*Turn left* (south) and proceed uphill in the direction of the conveyer along the eastern limb of the Vly anticline. Exposures of the upper part of the New Scotland Formation are on the right (west), and the Glenerie, Alsen, and Port Ewen Formations form the cliff faces to the left (east).
1.1	0.5	*Bear left* (east). The road passes through the Victoria thrust.
1.2	0.1	*Turn left* (north) east of crusher building, and proceed past the conveyer.
1.3	0.1	Park vehicles next to the *wash house*. Walk 1200 feet east along the north side of the conveyor. Stop at the ridge crest above the Lehigh plant and the Hudson River. This ridge is the easternmost exposure of the Helderberg Group on the west side of the Hudson River. We are standing on the eastern limb of the Alsen syncline.

The purpose of this stop is to examine the exposure along the north side of the conveyer (Figure 24b) where the strata of the lower Helderberg Group (Manlius, Coeymans, Kalkberg) are vertical or overturned to the west. The Manlius has been thrust over the lower Kalkberg. The Kalkberg of the footwall is imbricated by a single fault on which separation is only about 1 m. This fault appears to rejoin the overlying thrust at a branchline, thereby enclosing a horse of Kalkberg. About 5 m of Coeymans which has been folded by "drag" associated with movement on a still higher fault, overlies the Manlius in the hanging wall above the thrust. This thrust surface dips steeply to the west (N16°E, 80°W) and the dihedral angle between the fault and bedding is only 14°. This thrust cuts up-section to the west, which is consistent with the west vergence of the HVB. This relation is best visualized by rotating the sketch of the outcrop such that bedding is horizontal and right-side up.

The relationships at this exposure suggest west-directed thrust propagation within the Helderberg Group followed by regional folding which produced the Alsen syncline. Regional folding involved the Ordovician Austin Glen, which is not observed to be involved in the thrusting in this area. The regional folds at Cementon, therefore, support the concept of a blind thrust at depth in the Ordovician section. Movement on this thrust folded the overlying faulted Helderberg Group.

Return to vehicles, and retrace route to the quarry entrance. **End.**

Cum. Miles	Miles	
13.2	0.0	*Entrance to Lehigh quarry* (again). Retrace route, proceeding north on Route 9W. (Note: The next destination is the entrance to the New York State Thruway at Exit 21, and, after that, the Kingston exit on the Thruway. If desired, you can skip the log up to mileage 49.3 and instead just follow scenic Route 9W down to Kingston.)
13.8	0.6	*Entrance to Independent Cement Corporation Plant* (again).
17.7	3.9	*Junction of Route 9W and 23A* (again). Turn right and proceed north on 9W.
18.0	0.3	*Shopping plaza on the south side of Route 9W.*
18.1	0.1	*Stoplight.* Proceed through light and continue north on 9W.
18.2	0.1	*Junction of 9W with Route 385.* Bear left and continue north on 9W.
18.8	0.6	Cross under the *railroad bridge.*
18.9	0.1	*Bridge over Catskill Creek.*
19.4	0.5	Drive under the *Route 23 bridge.*
19.5	0.1	*Exit* on right to Route 23. Take this exit (off 9W) and proceed on ramp to the junction of this ramp with Route 23. At this junction, turn right onto Route 23 and follow signs to New York State Thruway.
21.0	1.5	*Exit* Route 23 onto 23B toward Leeds. (Roadcut N5 is at this exit; see Stop 1 description.) Turn right onto Route 23B, and proceed northwest toward Leeds.
21.5	0.5	*Access road* to New York Thruway (Route 87) entrance. Turn right off 23B and proceed to the tollgate.
21.7	0.2	Exit 21 *tollgate.* Take a ticket and follow signs to New York Thruway southbound (toward

Cum. Miles	Miles	
		New York City). On the east side of the Thruway, just north of the entrance-ramp bridge, there is a roadcut in which the New Scotland Formation has been thrust over itself with a pronounced angular discordance between strata of the hanging wall and footwall.
		Between Catskill and Kingston, the Thruway runs along the strike of the Hudson Valley fold-thrust belt. The ridges in the middle distance to the west are Mount Marion Formation on the face of the Hooge Berg, and the Catskill Mountains are in the far distance to the west. For a guide to the stratigraphy exposed in Thruway roadcuts, see Supplement C, **Geology of Thruway Roadcuts between Exits 21 and 19**, at the end of the roadlog.
29.7	8.0	*Roadcut* exposing the trace of a thrust fault in the Schoharie Formation.
39.9	10.2	Entrance to *service area.*
42.2	2.3	*Roadcut* exposing the lower part of the Mount Marion Formation or upper part of the Bakoven Shale.
44.6	2.4	Take Thruway *Exit 19* to the city of Kingston. Stops in the Kingston area provide additional examples of thin-skinned structures and evidence that the change in trend of the foldbelt at Kingston is an orocline resulting from the overprint of two non-coaxial thrusting events. Inherent in this model is the proposal that the Kingston area can be divided into three structural domains (northern, central, southern) as described earlier in this report.
45.4	0.8	Exit 19 *tollgate.*
45.5	0.1	*Junction* of tollgate access road with the traffic circle. Take the first right off the circle (exit for Pine Hill) and proceed on Route 28 across the Thruway. Proceed through stop light to exit for Route 209.
45.9	0.4	*Exit ramp* off Route 28 to Route 209 north (toward Rhinecliff Bridge).

Directions to **Optional Stop D**

Cum. Miles	Miles	
0.0	0.0	*Exit ramp* off Route 28 to Route 209 north. Continue west on Route 28, and cross Route 209.
0.4	0.4	**Stop D:** *Roadcut* on north side of Route 28 (below the Skytop Motel). Exposure of Bakoven Shale (or lower Mount Marion Formation?) in which there are a number of mesoscopic-scale schuppen or shear zones, as described by Bosworth (1984) and Nickelsen (1986). The presence of these shear zones, which are only about 10-15 cm in width, is evidence of blind thrusting in strata of the base of the Hamilton Group.
		Make a U-turn and return to Route 209. Take the exit off Route 28 that puts you on Route 209 north, toward the Rhinecliff Bridge. **End.**

45.9	0.0	Mileage restarts at the *exit* off Route 28 to Route 209 north (toward Rhinecliff Bridge), as if optional stop D was not taken. Turn off Route 28 and enter Route 209 north and east toward the Rhinecliff Bridge.
46.1	0.2	*Base of the entrance ramp* from Route 28 west onto Route 209 north.
48.3	2.2	*Bridge* over New York State Thruway.
48.7	0.4	*Bridge* over Esopus Creek.
48.8	0.1	*Exit* for Neighborhood Road. Continue on 209.
49.3	0.5	*Exit* for Route 9W south. Route 209 becomes Route 199. Continue east on Route 199 east (do not exit).
49.8	0.5	*Roadcut* exposure on 199 showing broad open anticline involving the Schoharie Formation and the Onondaga Limestone.
50.2	0.4	**Stop 6:** *Pull off onto the shoulder* of Route 199. The geology at this stop was described by McEachran (1985). A large anticline is visible from this locality (Figure 17a). The core of this fold contains the upper part of the Becraft Limestone, and it is overlain by the Alsen and Port Ewen Formations. Note the lithologic control on cleavage development (no cleavage in Becraft; good cleavage in Alsen and Port Ewen) and the consistent southeast-dip of cleavage domains, even on the west limb of the fold. The outcrops along Route 199 display large open folds, no visible thrust faults, and no obvious exposures of faults or of mesoscopic folding. Five major fold hinges are visible along Route 199 between Route 9W and Route 32. These are open folds that are slightly asymmetric (Plate 3; Figure 19a). The

Cum. Miles **Miles**

structures are more complex in the woods just to the south of 199 and just west of the escarpment. Structures of the Route 199 roadcuts are characteristic of the "northern domain" of the Kingston orocline; they have north-south to N15°E-trending structures and lack structural complexity. **End.**

Board vehicles and proceed a short distance further east on 199. We pass westward dipping beds of Manlius through New Scotland Formations. Take the exit to the right for Route 32.

50.5 0.3 *Exit* for Route 32. Turn right and proceed to the end of the ramp.

50.8 0.3 *Junction* of the exit ramp with Route 32. Either park in the lot directly across Route 32 or turn left and proceed south on Route 32.

51.2 0.4 **Stop 7:** *Pull off on right shoulder* (if you didn't park in the lot). Roadcut on the west side of Route 32 exposes imbricate thrust sheets of Rondout through Coeymans Formations. This exposure was first described in detail by Waines and Hoar (1967) and was further interpreted by McEachran (1985). The outcrop contains four major thrust faults which result in the repetition of the Rondout and Manlius Formations (Figure 25). Numerous minor thrust faults also occur in the outcrop. At the south end of the outcrop, beds of the Coeymans and Manlius dip 20° SW. In the middle portion of the outcrop, a thrust sheet composed of the Rosendale Member through Manlius Limestones is thrust over a 3 m-thick horse of Glasco Formation. The Glasco horse is itself thrust over Rosendale through Whiteport Members, and these units are thrust over the Coeymans and Manlius Formations. The faults in this outcrop generally strike N40°W and differ from the regional structural grain in the northern Kingston region. Calcite slip fibers on the faults suggest that the transport direction on the faults was N60°–70°W.

Cum. Miles **Miles**

Some of these faults parallel bedding both above and below the faults (i.e., they represent flat on flat geometries). These geometries suggest large displacement on the faults. Some of the faults appear to cut down-section in the footwall, as represented on the figure, but this apparent geometry is an artifact of the relative orientation of the outcrop face and the structure (the roadcut provides an oblique section). Remember that movement on faults carried the hanging wall *into* the outcrop (check the slip lineations!), so it is not always possible to match beds across the fault by searching the face of the outcrop.

The geometry of this outcrop gives a sense of the structural complexity found along the Helderberg Escarpment in the central domain. These faults could not be traced away from the roadcut but may ramp laterally up-section and die out to the north. **End.**

Board vehicles and proceed south on Route 32.

51.8 0.6 *Junction* with road into village of East Kingston. Turn left and proceed south into East Kingston. (At the intersection, Route 32 curves to the right and goes uphill; you should have turned left before going uphill on Route 32).

52.3 0.5 *Firehouse* in East Kingston. (Optional parking spot.)

52.4 0.1 *Stop sign.* Proceed straight on Devil's Lake Road.

52.7 0.3 First *quarry entrance* on left. (There are also spectacular quarries on the right. See descriptions in McEachran, 1985.)

52.9 0.2 **Stop 8:** Quarry near East Kingston. Second *quarry entrance* on left. Leave vehicles if someone can stay with them to avoid ticketing; otherwise, park in East Kingston near the firehouse and walk to this locality. If you have permission, pass through the gates on the east

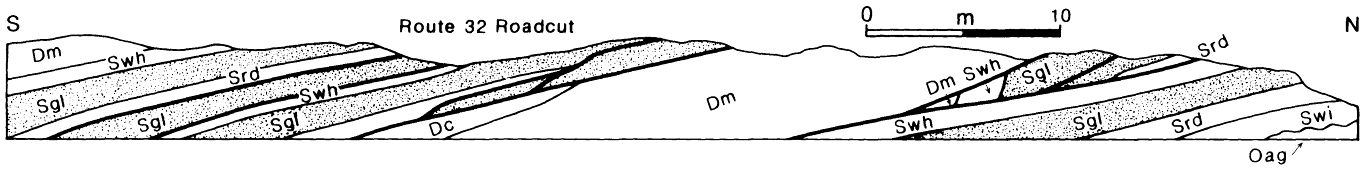


Figure 25: The Route 32 roadcut just south of Route 199. Note the thrusts duplicating members of the Rondout Formation (adapted from Waines and Hoar, 1967; McEachran, 1985). Oag = Austin Glen Fm.; Swi = Wilbur member; Srd = Rosendale member; Sgl = Glasco member; Swh = Whiteport member; Dm = Manlius Fm.; Dc = Coeymans Fm.

Cum. Miles **Miles**

side of the road and enter the large quarry (Figure 26a). This quarry lies between Devil's Lake Road and the Hudson River.

After entering the quarry from Devil's Lake Road, follow the wide dirt road toward the southeast; a deep pit is on the left. After about 100 m, the road curves sharply left and heads about 200 m northeast towards equipment garages. Turn sharply right at the equipment garage and walk about 200 m due south along a small dirt road into a large pit now partly filled by a lake. (This locality is the Lake Quarry.) As you face south, standing at the north end of the Lake Quarry, there is a narrow high ridge on your left (east). On the top of the ridge, there is a very large water tank. East of the ridge, there is an abandoned cement factory. We will look at several features in the Lake Quarry area.

First, note that the high wall to the south of the lake displays a large syncline-anticline pair. These folds are tighter than those found along Route 199. In the core of the syncline, there is a small out-of-the-syncline thrust on which Manlius has been imbricated. The quarry wall to the north of the lake (locality 1 in Figure 26a) displays a large tight anticline cored by Austin Glen Formation overlain by Rondout (Figure 26b). Note that the Ordovician rocks have not been thrust over the Silurian rocks, but that thrust faults appear to arise from a detachment at or near the unconformity. McEachran (1985) suggested that this detachment is the Rondout detachment. Structural relationships at this outcrop support the proposal that the Rondout detachment acts as the basal detachment of the thrust system involving the Silurian-Devonian carbonate sequence above the Taconic unconformity to the west of the Helderberg escarpment; shortening above still deeper detachment ("Austin Glen detachment") at depth in the Ordovician sequence is responsible for the development of the large anticline.

On the north side of the road which runs east through the ridge to the cement plant there is an exposure of two thrust faults which rise out of the Austin Glen Formation and emplace it over the lower 2 meters of the Rondout (locality 2 in Figure 26a). Note how these faults cut directly across bedding of the Austin Glen (Figure 26c). These faults are clear ex-

Cum. Miles **Miles**

amples of ramps rising out of the Ordovician strata, and their occurrence suggests that in the region to the east of the Helderberg escarpment, faults that root in the Austin Glen detachment may cut across the Taconic unconformity.

Walk south following the dirt road that runs along the western base of the ridge below the water tank (the east side of the ridge is the Helderberg escarpment). Continue uphill and pass the south end of the Lake Quarry. Enter the smaller quarry that lies south of the Lake Quarry. (We will call this quarry "Rampart.") As you stand at the north end of Rampart Quarry and face south, the Helderberg Escarpment lies just to your left (east). To your right (west), an east-west roadcut provides a cross-sectional exposure through a large syncline-anticline pair. The road follows the trace of a small tear fault; the hinge locations of the folds do not match across the road. Walk west (uphill) on the road (locality 3 in Figure 26a). The cut exposes the Becraft, Alsen, Port Ewen, and Connelly Formations. Excellent examples of out-of-the-syncline thrusts which imbricate the Becraft Limestone occur in the core of the syncline south of the road.

If time permits, walk back east to the north end of Rampart Quarry, turn right, and walk south into the quarry. The quarry floor and west wall expose a ramp which imbricates the Becraft.

Retrace your route and return to the vehicles. (The east-west road at the north end of Rampart Quarry extends west back to Devil's Lake Road. At the junction, there is an electric transformer station. If it can be organized, drivers can, alternatively, pick up people at the electric transformer substation, locality 4 in Figure 26a.) **End.**

Board vehicles. Make a U-turn and retrace route back to Route 32.

53.4 0.5 *Stop Sign* in East Kingston (again).

54.1 0.7 *Junction* with Route 32 (again). Take sharp left onto Route 32 and proceed south (uphill) on 32.

54.6 0.5 Vertical beds of Becraft and Alsen in the *road-cuts*.

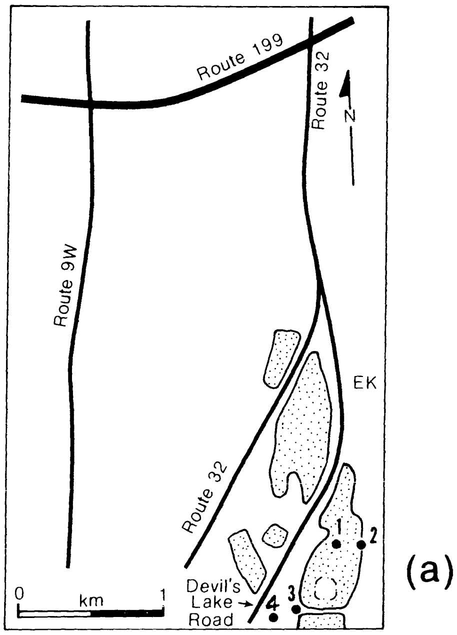
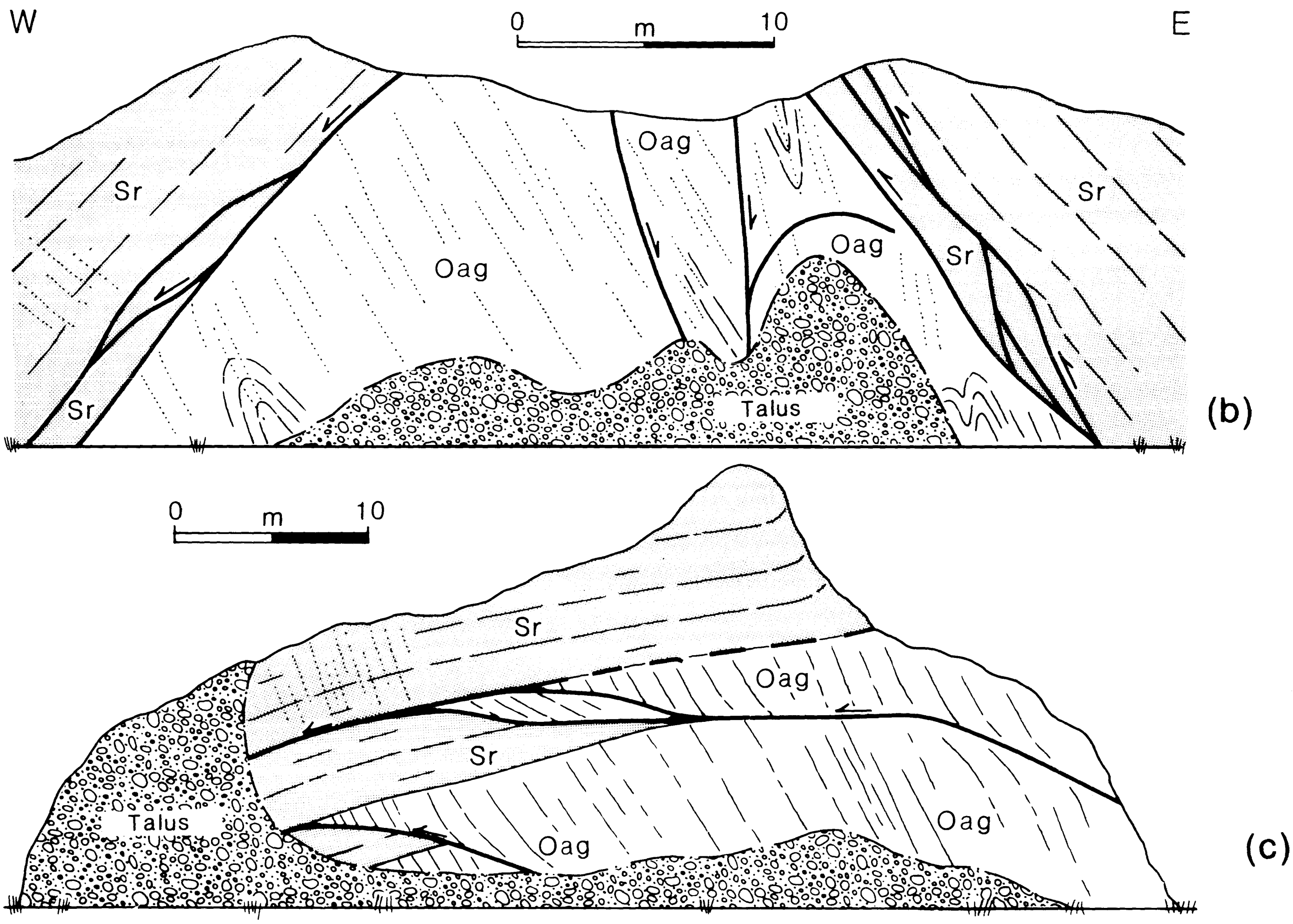


Figure 26: Exposures in the East Kingston quarries (modified from McEachran, 1985). (a) Location map showing the position of the quarries. Numbered localities are described in the text. (b) Ordovician-cored anticline, with the Rondout detachment on the limbs. (c) Ramps rising out of the Austin Glen Formation, emplacing Austin Glen over Rondout.



55.4 0.8 *Stoplight*. Proceed through the stoplight and immediately get in the left lane.

55.6 0.2 *Junction of Route 32 with Route 9W south.* Route 9W is a divided highway south of this junction.

Directions to **Optional Stop E**

Cum. Miles	**Miles**	
0.0	0.0	*Junction of Route 32 with Route 9W* (divided highway). Continue west (past the small cemetery on the right) on Route 32 to the stoplight. (For this short interval, Route 32 and Route 9W are the same.) Drive past small cuts in Esopus and Schoharie.
0.2	0.2	*Stoplight* at the junction of Route 32 with Route 9W. A large public building is in the northwest corner, and there are commercial buildings to the south. Turn right onto Route 9W and proceed north for a short distance.
0.3	0.1	**Stop E:** A *roadcut* in Onondaga Limestone. Park on the right.

Climb up to the top of the outcrop. Two distinct non-parallel sets of cleavage occur on the top bedding plane of this outcrop. The more northerly trending set appears to crosscut the northeasterly trending set. Note that the domains of the more northerly trending set tend to be thicker and more continuous than those of the other. It is possible that the thicker domains were initiated before the thinner domains but remained active during the formation of the thinner domains and thus offset them (Marshak and Tabor, 1989).

Return to vehicles. Make a U-turn (you may have to drive north on 9W for a short distance before a safe U-turn can be made) and retrace your route to the Junction between Route 32 and the divided highway segment of Route 9W.

Cum. Miles **Miles**

55.6 0.0 *Junction of Route 32 with 9W* (divided highway). Mileage starts as if Stop E was not visited.

Turn left and proceed south on 9W. Outcrops in the roadcuts are Schoharie and Onondaga.

56.7 1.1 **Stop 9:** *Pull off* on right-hand (west) shoulder and park just before the exit ramp for Delaware Avenue. (Park by the big green "Delaware Avenue" exit sign.)

There are two significant thrust faults at this stop. These faults have a relatively large stratigraphic throw. The lower one (exposed further to the north along the roadcut) emplaces Onondaga on Schoharie (Plate 3). The upper one (which is now covered by the exit ramp) emplaces Esopus on Schoharie and Onondaga. The upper fault may be the northern continuation of the Fly Mountain thrust.

If time permits, walk up the ramp to Delaware Avenue. An outcrop of Esopus Shale is present at the top of the ramp along the north side of Delaware Avenue and just west of the bridge over 9W. The interesting feature of this outcrop is the cleavage which appears to transect the principal structural grain of the region (i.e., cleavage is not axial planar to the folds of the area). South of the Delaware Avenue bridge, along 9W south, a syncline involving the Esopus is exposed in the roadcut. **End.**

Board vehicles. Take the Delaware Avenue exit off Route 9W. (Participants can board vehicles at the top of the ramp, if desired.)

57.0 0.3 *Stoplight* at the end of the exit ramp. Turn left (east) onto Delaware Avenue. Cross Route 9W. Just over bridge, turn sharply right to stay on Delaware Avenue. Continue east on Delaware Avenue.

57.3 0.3 Immaculate Conception *Church* on right.

57.5 0.2 **Stop 10:** Turn right into hidden *entrance to Hasbrouck Park.* (This turn-off is just before Delaware Avenue begins to descend steeply over the Helderberg Escarpment. It is just west of the most easterly house before the escarpment.) The geology of the Hasbrouck Park area is quite complex and makes an excellent map exercise for students (Figure 27). It should be mapped at a scale of 1:2400. (Inexpensive air photos of the park at this scale can be obtained in Kingston at the county tax office.)

Along the east edge of the park is a very steep and dangerous cliff, the Helderberg Escarpment. There are old, very deep roof-and-pillar cement quarries at many localities. Structural relationships exposed along the cliff and in these quarries are fascinating and are worth examining, but such work must be

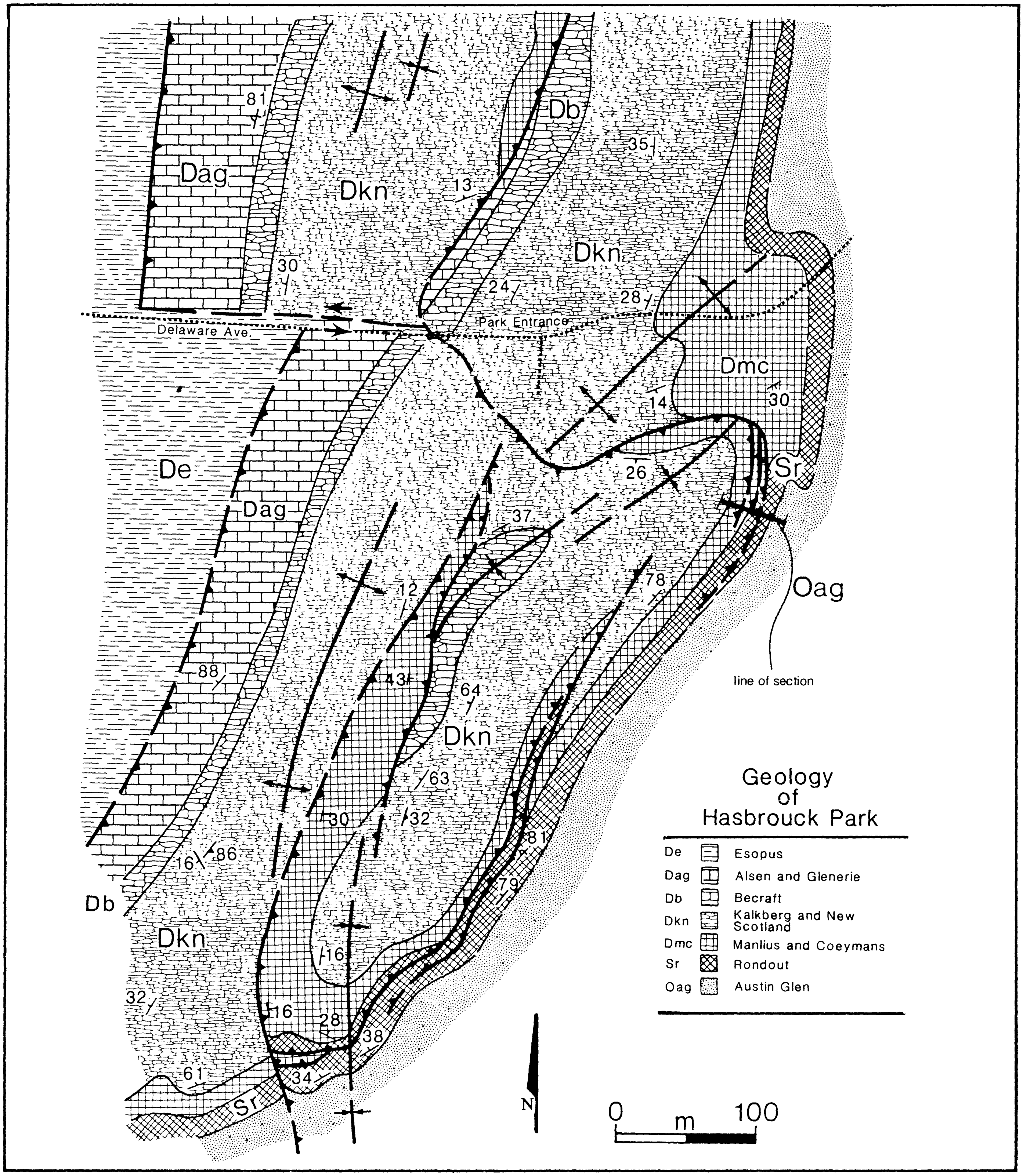


Figure 27: Simplified geologic map of the Hasbrouck Park area in Kingston (from Marshak and Tabor, 1989). Note the imbrication along the Helderberg escarpment, the backthrusting, and the tear fault.

Cum. Miles	Miles	
		done very carefully. It is possible to see both backthrusts and forethrusts which multiply imbricate the Rondout and Manlius. Tight folding occurs adjacent to some of the faults. At some localities along the scarp, the vertical to overturned limb of a fold forms the entire face of the scarp (i.e., a wall that is about 30 m high). The structural geometry displayed in the park is much more complex than any we have seen along the Helderberg Escarpment to the north.
		Disembark from vehicles about 50 m south of the entrance, walk east past the abandoned wading pool, and follow the path into the woods. Outcrops of the Manlius, Coeymans, and Kalkberg formations are on the right. Within 100 m, the path descends to a small tunnel-like quarry that has been partially walled. There are good examples of the imbrication and associated folding that characterizes the Helderberg Escarpment at this locality above this quarry and along the cliff face to the south. This cut provides a section through the leading edge of a duplex of horses involving the Rondout through Kalkberg (Figure 28). The basal thrust of this sequence (the Hasbrouck thrust) cuts laterally upsection along the path through the woods and reap-

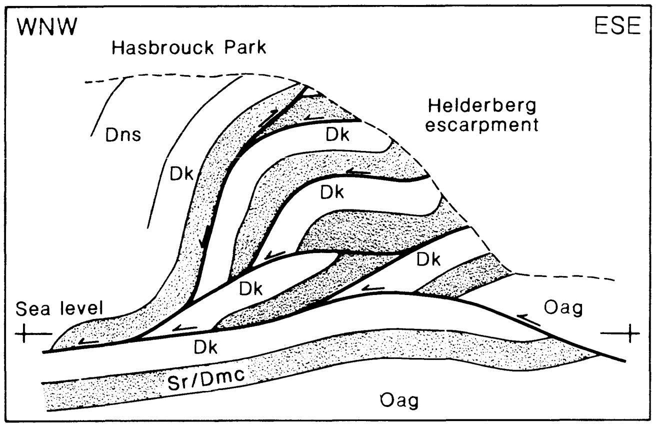


Figure 28: Diagrammatic cross-section sketch, not to scale, of the Helderberg escarpment at the northeast corner of Hasbrouck Park. Approximate location of this section is indicated on Figure 27.

pears north of Delaware Avenue where it emplaces beds of the Manlius Formation above the Alsen Formation (at the top of a large roof-and-pillar quarry). A tear fault with its trace roughly coincident with the Delaware Avenue may extend to the west of the lateral ramp (Figure 27).

Cum. Miles	Miles	
		From this locality, you can creep south along the base of the escarpment to observe the overturned beds that form the escarpment, or you can retrace your path to the vehicles near the wading pool. Vehicles can then proceed south to the end of the park access road and turn around in the gravel lot at the overlook.
57.9	0.4	*Overlook* at the south end of Hasbrouck Park. From this locality, you get a good view of Hussey Hill to the south. Hussey Hill is composed of steep to overturned strata of the Quassaic Formation (see Waines, and others, 1983; 1987). Return to park entrance. **End.**
58.2	0.3	*Junction* of Park access road with Delaware Avenue. Turn left onto Delaware Avenue and follow Delaware Avenue west back to Route 9W.
58.5	0.3	*Stoplight.* Turn left and cross over Route 9W.
58.6	0.1	*Stoplight.* Entrance to Route 9W south. Turn right and proceed down the ramp to Route 9W south. Proceed on Route 9W south through two sets of lights.
59.3	0.7	*New bridge* over Rondout Creek. On the south side of the bridge, large roadcuts expose Ordovician graywacke (lithic arenite) with interesting synsedimentary structures as well as post-lithification faults.
59.9	0.6	*Center* of the village of Port Ewen. Turn right on Salem Street (county road 25). Proceed southwest on Salem Street.
60.8	0.9	*Junction* with Millbrook Road. Continue on Salem Street.
61.2	0.4	Cross *railroad tracks* and take sharp bend to the right. On your left is Hussey Hill with a radio tower on top.
62.1	0.9	**Stop 11:** *Entrance to Callanan Quarry* (near Connelly). Park at head office and obtain permission. Leave vehicles and follow the road into the quarry. Bear right and stay on the upper shelf. Proceed to the east end of the quarry. Most of our discussion will concern relations visible on the large northeast wall of the quarry (Figure 29). These relations are best observed from a distance.

Cum. Miles	Miles	
		The northeast wall was cut almost perpendicular to strike and provides a remarkable cross-section view of the fold-thrust belt structure between the Helderberg Escarpment and Rondout Creek. The east end of the wall exposes nearly vertical beds of Rondout through New Scotland in which there are numerous bedding plane slip horizons. The underlying Taconic unconformity is covered but presumably is vertically dipping as well. Note that less than 1 km to the south is Hussey Hill (the northern end of the Marlboro Hills), which attains an elevation of over 300 m.
		The upper part of the Becraft Limestone (the light gray coarse-grained limestone) appears three times in the right half of the quarry wall because of movement on two thrust faults. These faults are backthrusts, responsible for moving the hanging wall to the southeast, in a direction opposite to the regional vergence.
		Proceeding to the northwest along the wall, we pass into the core of a broad syncline that involves units up through the Port Ewen. At the core of the syncline there are out-of-the-syncline thrusts which imbricate beds of the Port Ewen Formation.
		Still further to the west, near the base of the outcrop, there is a west-directed ramp that follows the Becraft-Alsen contact, then cuts upsection across the lower portion of the Alsen, and disappears into the bedding of the Alsen Formation. In the hanging wall of this fault, there is an excellent example of a hanging-wall anticline composed of Alsen. A backthrust cuts upsection from the northwest limb of the anticline.
		Look back westward toward the crushing equipment at the southwest end of the quarry.

Cum. Miles	Miles	
		To the right of the road that leads down into the deep pit is a high ridge that separates the pit from the creek. This ridge contains a syncline-anticline pair, but much of the anticline has been removed by the quarry operations. The anticline is cored by Austin Glen and is asymmetric and tight. Its hinge may be bent in plan view. **End.**
		Board vehicles. Turn right and continue on Salem Road (County Road 25) to the southwest.
63.1	1.0	*Junction* with Route 213. Turn right onto Route 213. A large outcrop of Austin Glen Formation is on your left.
63.2	0.1	*Bridge* over Rondout Creek. Continue northeast on Route 213. The large cliff straight ahead is the Helderberg Escarpment, which forms the southeast edge of Fly Mountain. The structures of Fly Mountain have been described by Tabor (1985).
		Most of Fly Mountain appears to be allochthonous (Davis, 1883c; Waines, pers. comm. 1984; Tabor, 1985). It is underlain by the Fly Mountain thrust which emplaces Martinsburg through Port Ewen over lower Devonian strata (Figure 30a). Displacement on the fault increases to the southwest. It appears that this fault truncates earlier folds (Tabor, 1985). There appear to be at least two repetitions of Ordovician strata on the face of the escarpment to the southwest of Wilbur. The stratigraphic throw on the Fly Mountain thrust along Fly Mountain is greater than the throw on any fault further to the north. From Wilbur south, the structural grain has a more northeasterly trend than it does to the north. The swing in orientation of structural grain, in fact, starts north of Hasbrouck Park. Southwest of

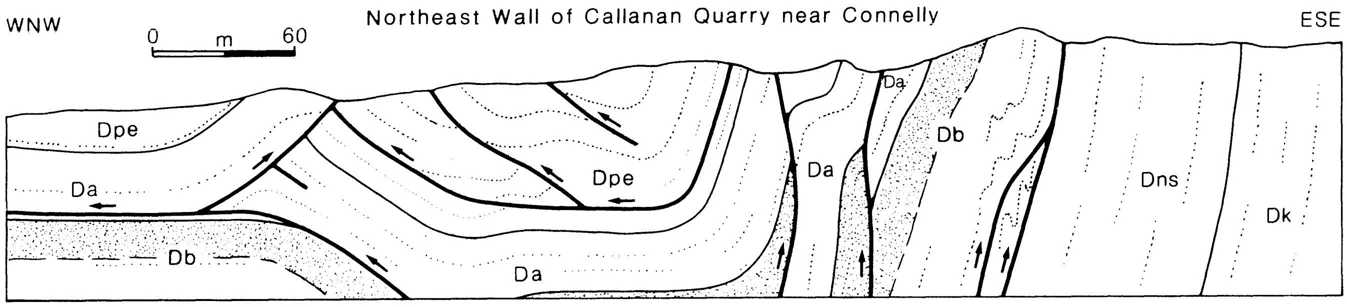
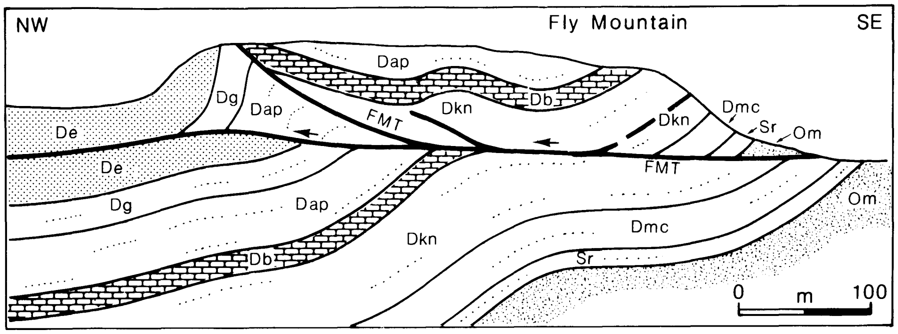
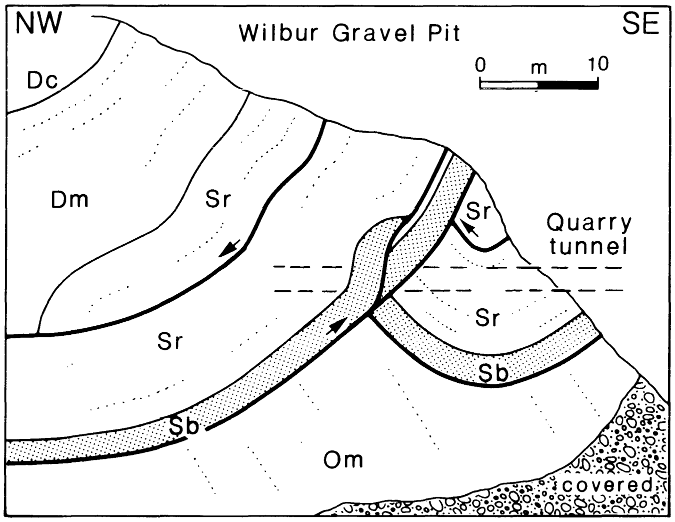


Figure 29: Cross-section diagram of the north wall of the Callanan quarry in Connelly (from Marshak and Tabor, 1989). The upper part of the Becraft is shaded. Note both backthrusts repeating the upper Becraft and the out-of-the-syncline faulting in the Dpe. Dk = Kalkberg; Dns = New Scotland; Db = Becraft; Da = Alsen; Dpe = Port Ewen.

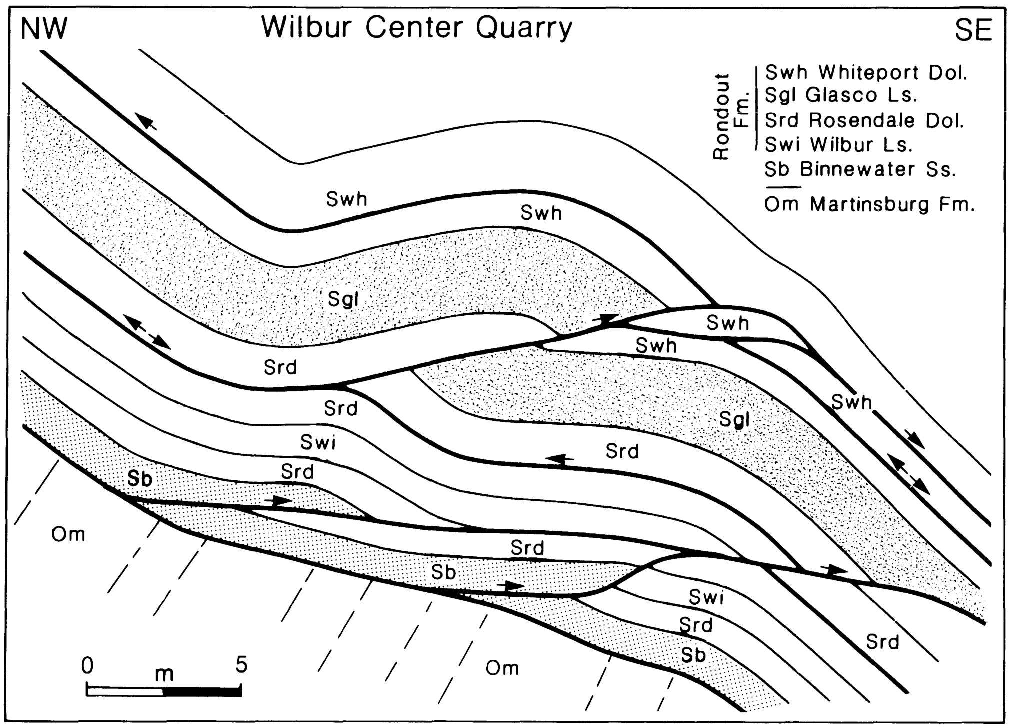


(a)



(b)

Figure 30: Exposures along the Helderberg Escarpment in Wilbur. Features in these sections are described in the text. (a) Cross section of Fly Mountain. FMT = Fly Mountain thrust (from Marshak and Tabor, 1989). (b) Cross-section sketch of the escarpment at the Wilbur Gravel pit (from Marshak and Tabor, 1989). (c) Cross-section sketch of the escarpment in central Wilbur. Double arrows indicate occurrence of west-verging then east-verging (backthrust) movement on the same surface (adapted from Tabor, 1985).



(c)

Cum. Miles **Miles**

Fly Mountain (i.e., the southern domain) the fold-thrust belt changes in character; shortening increases, structural relief increases, the thrust system propagates further into the foreland, and accommodation structures are less prevalent.

Southern domain structures can be viewed in the woods surrounding the Williams Lake Hotel, near the village of Rosendale a few miles further south. Permission to view these structures must be obtained from the owners of the hotel. Excellent exposures of the High Falls Shale are also present along Rondout Creek at the falls in the village of High Falls, several miles southwest of Rosendale. Description of the geological features visible in the streamcuts is provided by plaques in a small park on the bank of the stream.

Follow Route 213 around the curve and proceed northeast between the base of the escarpment and Rondout Creek.

64.0 0.8 *Pull-off* on right for bus parking. Cars could continue to next stop. (Bus passengers will have to walk).

64.2 0.2 **Stop 12:** *Entrance to Wilbur town gravel pit* on the left. (Small pull-off is available at the pit entrance). Park and walk up the short gravel road into the pit. The structural features of the Helderberg Escarpment at the gravel pit (Figure 30b) have been described by Tabor (1985, 1986). To reach the rocks, climb up the steep path at the south end of the gravel pit. At the top of the path, there is a tunnel that provides access to an old roof-and-pillar quarry.

In the tunnel, the Rondout Formation and the underlying Binnewater Sandstone are folded into a tight syncline. The northwest limb of this syncline is truncated by a backthrust which juxtaposes these two units; bedding in the hanging wall is almost perpendicular to bedding in the footwall. The Rondout that overlies the Binnewater in the hanging wall has been quarried out. The Rondout of the hanging wall is repeated by movement on a west-directed thrust. Where this thrust intersects the escarpment (which it does twice because of the backthrust described above), it displays a flat-on-flat configuration.

Once in the quarry, turn right (northeast) and proceed along the steep bedding surface

Cum. Miles **Miles**

out of the quarry and onto the face of the escarpment. A steep path provides access to a point higher on the escarpment where there are complex multiple backthrust imbrications of the Rondout. *It is dangerous in this area, so attempt reaching this outcrop only if you are a good climber and the rocks are not wet!* **End.**

Return to vehicles, and continue northeast on Route 213.

64.8 0.6 *Flashing light* in the center of the village of Wilbur.

64.9 0.1 **Stop 13:** *Wilbur Center outcrop.* An elaborate stone house is along the creek to the south of the road. The outcrop is the face of the escarpment to the north of the road. Around the corner to the northeast of the outcrop is a small abandoned quarry.

The escarpment behind the house has been described in detail by Tabor (1985); an unobstructed photograph of this outcrop is provided by Darton (1894c). The outcrop exposes Ordovician and Silurian strata (Figure 30c). The Silurian strata (Binnewater and Rondout) have been imbricated by movement on an array of thrust faults. The flat-on-flat geometry of some of these faults suggests substantial displacement. Some of the thrusts have been reactivated as backthrusts which transported strata toward the synclinal hinge that coincides approximately with Rondout Creek.

Exposures of the Manlius, Coeymans, and Kalkberg Formations occur around the corner in the old quarry. These units are folded into a non-cylindrical anticline. **End.**

Board vehicles. **End of trip.**

The trip through the Kingston area has provided an opportunity to examine structures in two of the three structural domains of the post-Taconic fold-thrust belt in the region. In the northern domain, we observed gentle, open folding and lack of structural complexity. In the central domain, we observed fault reactivation, cleavage overprints, non-cylindrical fold geometry, and numerous accommodation faults. We did not visit the southern domain but, as mentioned, southern domain structures can be viewed in the vicinity of Williams Lake and High Falls. Marshak and Tabor

Cum. Miles	Miles	
		(1989) argue that the northern domain represents the southern limit of the HVB (Acadian?) and that the southern domain represents the northeastern limit of a northeast-southwest trending Alleghenian fold-thrust belt that extends into the area from the Delaware Water Gap. The complex structures of the central domain represent the overprint of these two belts.
		Those with destinations to the south can make a U-turn and follow Route 213 southwest to the fork at which Route 153 takes off to the right. Route 153 will merge with Route 65 which will take you past the southwest end of Fly Mountain and eventually join Route 32 south to New Paltz. Those heading north or west should proceed on Route 213 northeast.
65.8	0.9	Head northeast on Route 213. Pass beneath *railroad bridge*.
66.3	0.5	*Flashing light*. Bear left, uphill, at this light onto Hudson Street. Follow Hudson Street until it becomes McEntee Street. Continue uphill on McEntee Street around the sharp bend to the left. McEntee Street becomes Broadway. Follow Broadway through downtown Kingston to the junction with Routes 28/587. Take Routes 28/587 west (a four-lane highway) to the traffic circle at Thruway Exit 19. Proceed to your home destination from this locality.

Supplement A: STOP SA — MOUNT IDA QUARRY

Cum. Miles	Miles	
		Head east on Route 23 (near Catskill) and cross to the east side of the Hudson River on the Rip Van Winkle Bridge. The log to this supplementary stop begins at the eastern end of the Rip Van Winkle Bridge.
0.0	0.0	*East end of the Rip Van Winkle Bridge*. Bear left, and prepare for a left-hand turn onto Route 9G.
0.5	0.5	*Junction of Route 23 with Route 9G*. Automobile dealership on the left. Turn left and head north toward the town of Hudson on Route 9G/23B.
0.9	0.4	*Exposures of Taconic Wildflysch in the roadcut* on the west side of the road. This outcrop, described by Ratcliffe and others (1975), is one of the best wildflysch exposures in the region. The hill to the west is possibly a slump block of chert from the Middle Ordovician Mount Merino Formation in the wildflysch (Bird, 1969). The wildflysch is thought to have been shed from the leading edge of the Giddings Brook slice of the Taconic allochthon, which lies just to the east.
2.6	1.7	*Hudson city limit*. Follow Route 9G into the city.
3.5	0.9	*Right turn* to stay on Route 9G/23B north.
4.1	0.6	*End of Route 9G*. Bear left and continue on Route 23B.
4.2	0.1	*Bear left* to stay on Route 9 and 23B.
4.6	0.4	*Junction*. Route 9 goes left. Do not turn, but continue straight on 23B.
4.7	0.1	*Junction of Route 23B with Route 66*. Turn left and head north on Route 66 toward Chatham.
6.6	1.9	*Large electric power line* crosses Route 66. Small hill to the northeast is Mount Ida.
7.2	0.6	*Turn right* off Route 66 onto the gravel road leading to "Keil Contracting." Drive 0.2 miles down the gravel road, park at the turnaround, then walk along the small road into the quarry.
7.4	0.2	**Supplemental Stop SA:** *Quarry at Mount Ida*. Description of this quarry is based on the work of Ratcliffe and others (1975). Mount Ida, and Becraft Mountain to the south, are small erosional outliers of the unmetamorphosed Silurian-Devonian strata which rest unconformably on Cambrian Hatch Hill Formation (slate, limestone, and conglomerate) of the Giddings Brook slice in the Taconic allochthon (Figure 31). *Note.* In earlier reports (e.g. Ratcliffe and others, 1975), this unit below the unconformity has been referred to the "Germantown Formation" of Fisher (1961). However, recent stratigraphic and biostratigraphic work emphasizes that the "Germantown" is the lithic and age equivalent of the Hatch Hill Formation in the central and northern part of the Giddings Brook slice of the Taconic allochthon. The designation "Hatch Hill Formation" (Theokritoff, 1959) is preferred for this interval of upper Lower Cambrian through lowest Ordovician black shales with dolomitic quartz arenites, thin

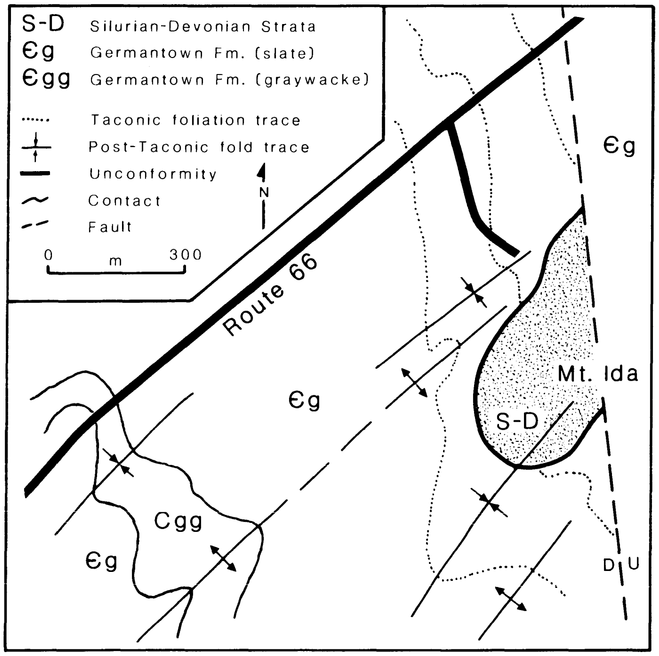


Figure 31: Geologic map of the Mount Ida area, illustrating post-Taconic folds in the Hatch Hill Formation (simplified from Ratcliffe and others, 1975). *Note.* The map retains the formation name "Germantown" that was used by the authors. Hatch Hill is the preferred name for this unit: see Supplemental Stop SA.

Cum. Miles Miles

limestones, and carbonate clast debris flows in the Giddings Brook slice (Landing, 1988b). Fisher's (1961) representative section of the "Germantown" on Routes 9 and 23 has been referred to the Hatch Hill Formation (Landing and others, 1986; Landing, 1988a). The lowest unit above the unconformity is the Manlius Limestone; in places, there is a sandy, conglomeratic, dolostone layer at the base of the Manlius, which might be correlative, at least lithologically, with the Rondout Formation that we saw west of the Hudson River.

A spaced solution cleavage is visible in the beds of Manlius Formation above the unconformity, and this cleavage differs in character and orientation from the slaty cleavage in the Hatch Hill Formation. A good exposure of this relationship is available at the entrance to the quarry, where clasts of slate can be found in the conglomeratic carbonate above the unconformity. Thus, the slaty cleavage developed before the deposition of the carbonate (Ratcliffe and others, 1975).

The cleavage of the Manlius Formation here is similar in orientation to cleavage in HVB rocks west of the river. Mapping by Ratcliffe and others (1975) and Ruedemann (1942) demonstrates that the Helderberg Group rocks are folded; the quarry exposes a large northeast-trending syncline that is truncated by a late high-angle fault. The fold trends are similar to but are not parallel with trends of folds to the west of the river. This folding also affected the underlying Hatch Hill Formation and can be recognized below the unconformity by mapping distinct conglomeratic layers of the Hatch Hill and by mapping the trace of Taconic foliation (Figure 31).

The relations at Mount Ida provide the evidence that Silurian-Devonian strata once extended well east of the Hudson River and that the structures of the HVB also affected the region that is now the Taconic Mountains. The position of this outlier indicates an arch in the Taconic unconformity at the position of the Hudson River; the river may follow the trace of a regional antiform.

Large quarried blocks of Manlius Limestone on the floor of the quarry provide an excellent opportunity to study the morphology and distribution of cleavage (Marshak and Geiser, 1980). It is possible to find examples of both sutured and non-sutured cleavage domains (see Marshak and Engelder, 1985) and to observe cleavage refraction.

Supplement B: STOP SB — QUARRY NEAR FEURA BUSH

Cum. Miles	Miles	
0.0	0.0	Take the exit from the New York State Thruway at Interchange 22 (Selkirk). Proceed through the *tollgate*, turn right, and proceed south on Route 144.
0.8	0.8	*Junction of Route 144 with Route 396* to Selkirk. Turn right and proceed west through Selkirk on Route 396.
3.7	2.9	*Junction of Route 396 with Beaver Dam Road.* Bear left and proceed west on Route 396. Cross Route 9W and proceed west on Route 396 through South Bethlehem.
7.8	4.1	*Junction of Route 396 with Route 102, Snyder Bridge Road.* Turn right off Route 396 and proceed north toward Feura Bush.
8.8	1.0	*Entrance to Albany Filtration Plant.*

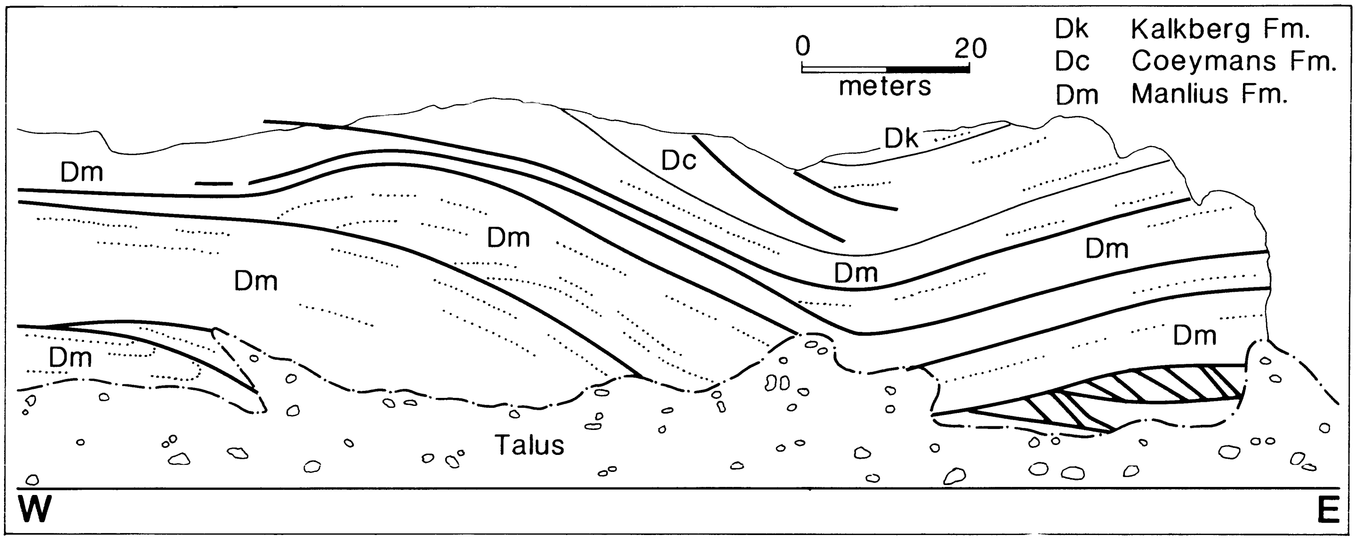


Figure 32: Cross-section sketch of the north wall of the quarry along the Helderberg Escarpment near Feura Bush (from Marshak, 1986a). Heavy lines are fault traces, dotted lines are bedding plane traces. Note the duplex in the lower right corner of the drawing and the hanging-wall anticline in the central part of the diagram.

Cum. Miles	Miles	
9.5	0.7	**Supplemental Stop B:** *Quarry near Feura Bush.* The quarry is now used as a shooting range for the local police department, and permission is required to enter the quarry. The quarry is not visible from the road. Park at the utility building and walk up the overgrown dirt road at the north end of the parking lot to find the quarry. There is a switchback halfway along the dirt road.

This quarry is cut into the Helderberg escarpment. It exposes one of the best examples of a ramp anticline over a fault bend that is known in the HVB (Figure 32). Strata of the Manlius through Kalkberg Formations have been thrust westwards on the fault. A syncline and complex mesoscopic folding developed in the footwall below the ramp. Darton (1894b) described a similar structure nearby where the Helderberg Escarpment is cut by Sprayt Creek. At the east edge of the quarry's north wall, the detachment is the roof thrust of a flat-roofed duplex involving the basal beds of the Manlius. This duplex contains a number of ramps which extend from the floor thrust to the roof thrust, a distance of only a few meters. **End.**

Supplement C: GEOLOGY OF THRUWAY ROADCUTS BETWEEN EXITS 21 AND 19

This log follows the stratigraphy of outcrops in the HVB along the New York State Thruway between the exit for Catskill (Exit 21) and the exit for Kingston (Exit 19). The positions of outcrops are indicated with respect to the mileposts on the Thruway (the tiny green signs along the side of the road). This log begins at the Catskill exit and proceeds south.

Milepost 114.5: Becraft and New Scotland Formations.

Milepost 112.9-112.7: Esopus Shale.

Milepost 112.3: Schoharie Formation.

Milepost 112.2-111.9: Esopus Shale.

Milepost 111.7: Schoharie Formation.

Milepost 111.4-111.3: Onondaga Limestone.

Milepost 111.1-110.7: Schoharie Formation.

Milepost 110.5: Onondaga Limestone.

Milepost 110.3: Schoharie Formation.

Milepost 109.4: Schoharie Formation.

Milepost 108.9: Contact between Schoharie and Esopus Formations.

Milepost 108.7: Schoharie Formation.

Milepost 108.4: Esopus Shale.

Milepost 106.7-106.3: Schoharie Formation.

Milepost 104.9-104.8: Onondaga Limestone.

Milepost 103.6: Schoharie Formation.
(Service Area)

Milepost 103.0-102.4: Becraft, Alsen, and Port Ewen Formations.

Milepost 102.0-101.9: Schoharie Formation.

(Exit for Saugerties)

Milepost 100.2-100.1: Onondaga Limestone.

Milepost 100.8: Onondaga Limestone.

Milepost 97.1: Mount Marion Formation.

Milepost 94.0: Mount Marion Formation.

Milepost 92.1: Mount Marion Formation.

Milepost 91.9-91.7: Mount Marion Formation.
(Exit for Kingston)

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APPENDIX: FOSSILS

These illustrations show many of the fossils found in the area of the HVB. The figures are reproduced from Goldring, 1943, The Geology of the Coxsackie Quadrangle, New York. The reproduction includes the original figure numbers and captions.

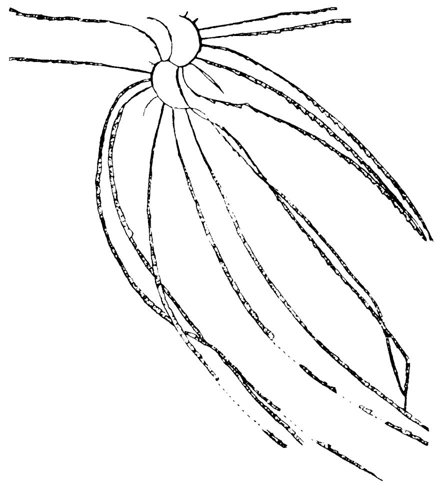

Figure 22 *Nemagraptus gracilis* (Hall). A diagnostic graptolite from the lower Normanskill formation (Mount Merino chert). A large specimen. (After Ruedemann)

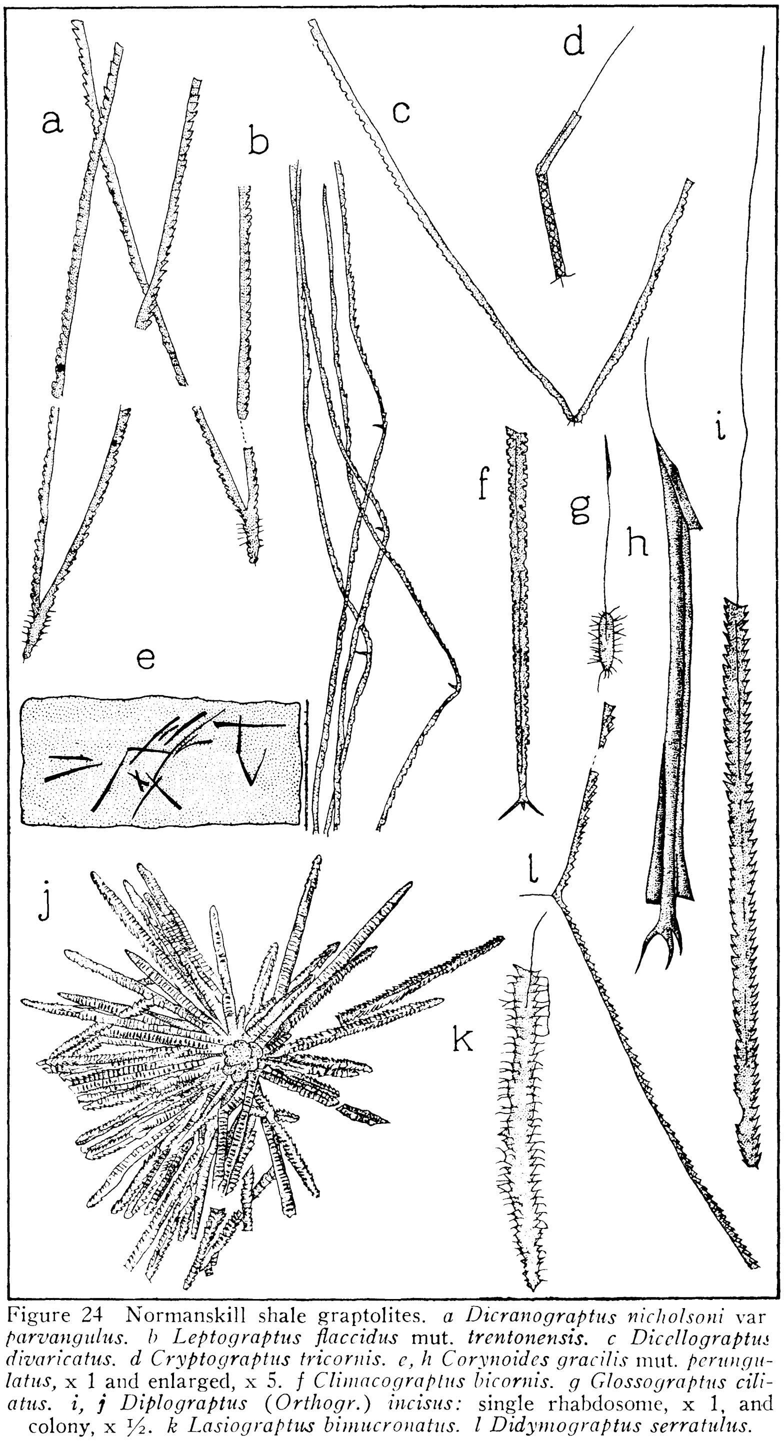

Figure 24 Normanskill shale graptolites. *a Dicranograptus nicholsoni* var *parvangulus*. *b Leptograptus flaccidus* mut. *trentonensis*. *c Dicellograptus divaricatus*. *d Cryptograptus tricornis*. *e, h Corynoides gracilis* mut. *perungulatus*, x 1 and enlarged, x 5. *f Climacograptus bicornis*. *g Glossograptus ciliatus*. *i, j Diplograptus (Orthogr.) incisus:* single rhabdosome, x 1, and colony, x ½. *k Lasiograptus bimucronatus*. *l Didymograptus serratulus*.

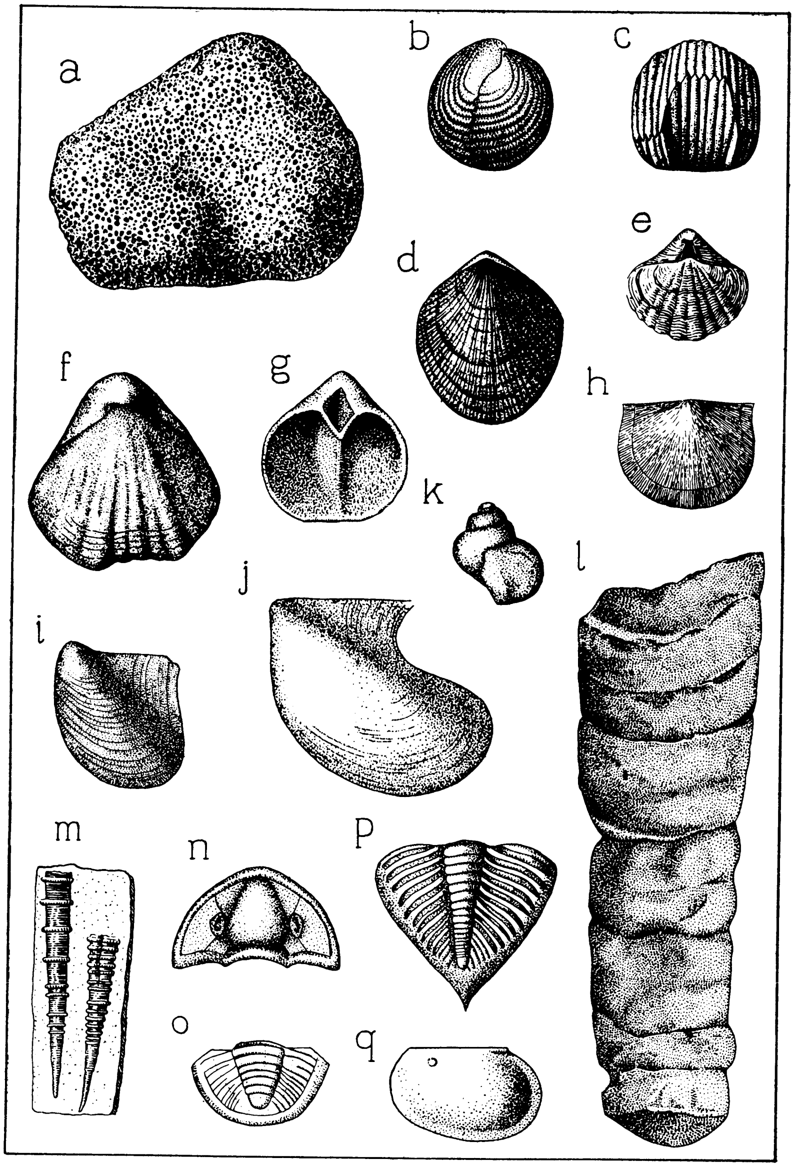

Figure 26 Manlius waterlime and Coeymans limestone fossils. (Manlius, *e, h, k, i, m, q.* Coral, *a;* brachiopods, *b-h;* pelecypods, *i, j;* gastropod, *k;* cephalopod, *l;* pteropod, *m;* trilobites, *n-p;* ostracod, *q*). *a Favosites helderbergiae,* x ½. *b, c Uncinulus mutabilis,* x ¾. *d Atrypa reticularis,* x ¾. *e "Spirifer" vanuxemi,* x 1½. *f, g Gypidula coeymanensis,* x ¾; interior of valve, x 1. *h Stropheodonta varistriata,* x ¾. *i Leiopteria aviculoidea. j Actinopteria obliquata,* x ¾. *k Holopea antiqua,* x ¾. *l "Orthoceras" (Anastomoceras) rudis,* x ½. *m Tentaculites gyracanthus,* x 2. *n, o Proetus protuberans,* head and pygidium, x 1. *p Dalmanites (Symphoria?) micrurus,* x ¾, q *Leperditia alta,* x 2.

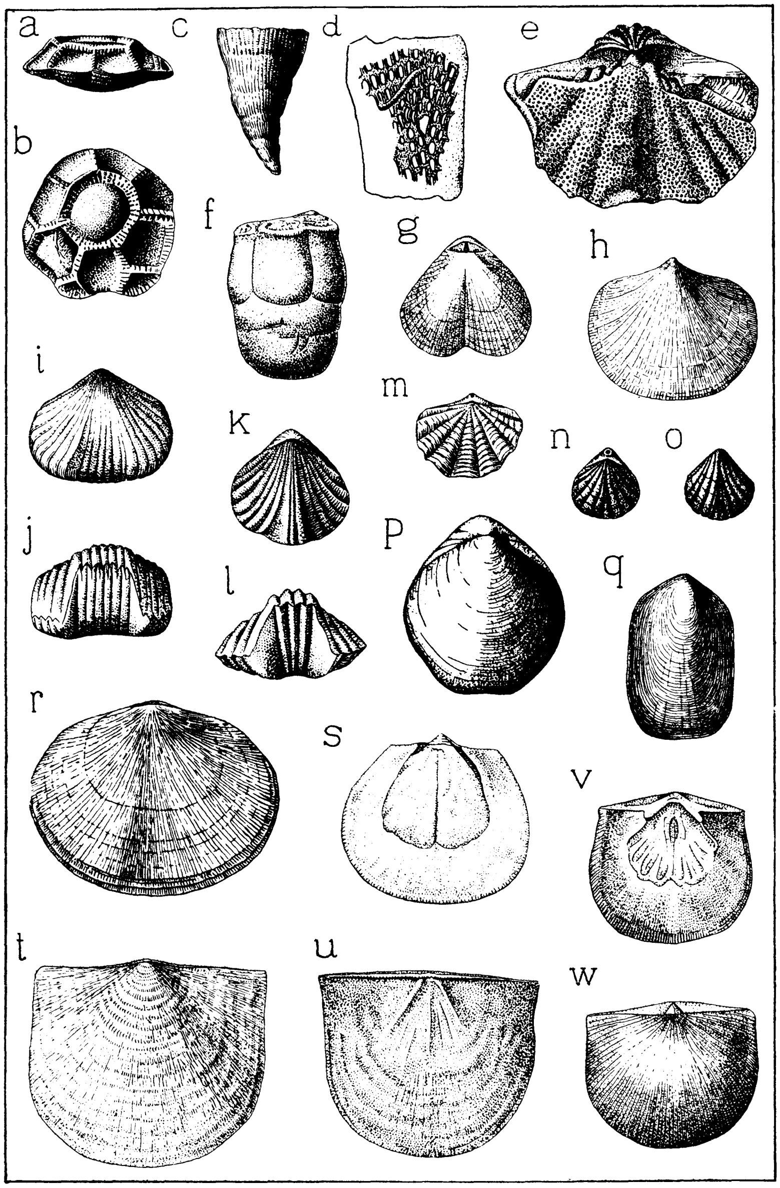

Figure 30 New Scotland beds fossils. (Kalkberg only, *g*. Corals, *a-c;* bryozoans, *d, e;* crinoid, *f;* brachiopods, *g-w*). *a, b* ***Michelinia lenticularis.*** *c Streptelasma* (*Enterolasma*) *strictum*, x ¾. *d* ***Fenestella compressa.*** *e* ***Paleschara*** *incrustans. f Edriocrinus pocilliformis*, x ¾. *g Bilobites varicus*, x 2. *h Isorthis perelegans*, x ¾. *i, j Uncinulus abruptus*, x ¾. *k, l Stenoschisma* ***formosum***, **x ¾.** ***m Atrypina imbricata***, x ¾. ***n, o Rhynchospira globosa.*** *p* ***Meristella laevis***, x ¾. *q Lingula rectilatera*, x ¾. ***r, s*** *Rhipidomella oblata*, x ¾, x 1. ***t, u Leptostrophia becki***, x ¾, x ½. *v, w Schuchertella* ***woolworthana***, x ¾.

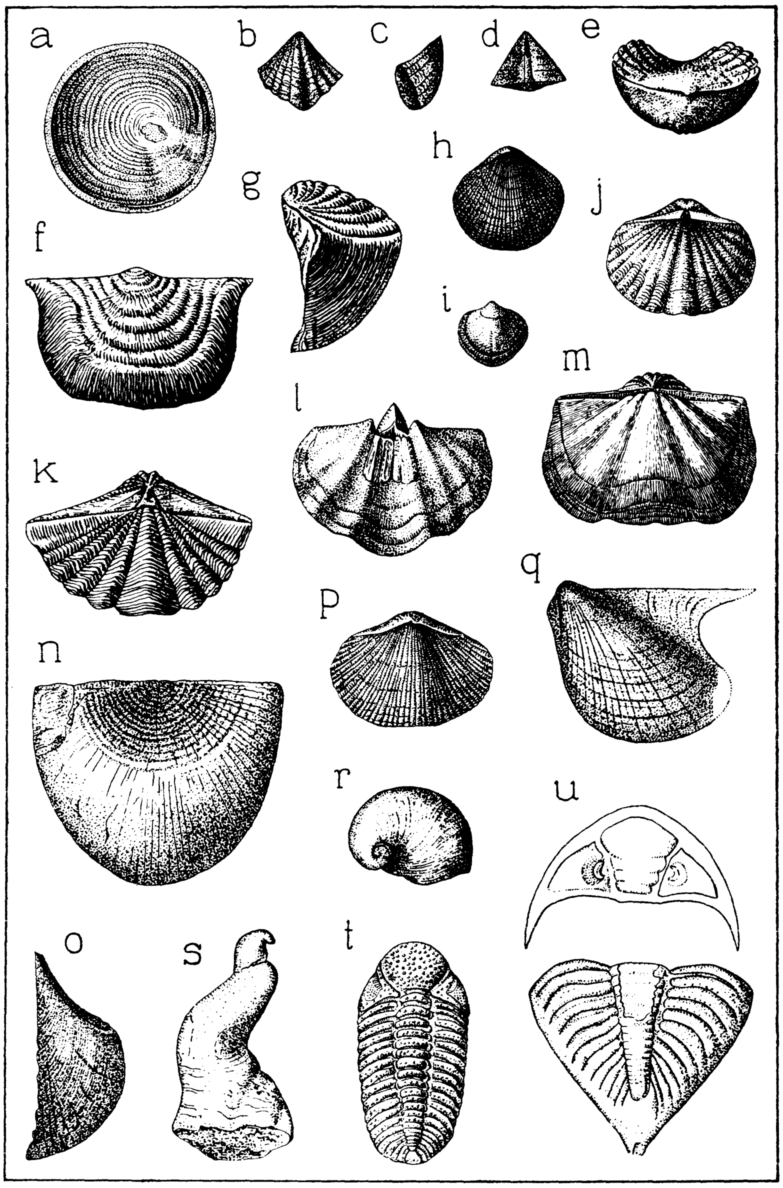

Figure 31 New Scotland beds fossils. (Brachiopods, *a-p;* **pelecypod,** *q;* gastropods, *r, s;* trilobites, *t, u*). *a Orbiculoidea discus,* x ¾. *b-d Cyrtina dalmani. e Eatonia medialis,* x ½. *f, g Leptaena rhomboidalis,* x ½. *h Parazyga deweyi,* x ¾. *i Nucleospira ventricosa,* x ½. *j "Spirifer" cyclopterus,* x ¾. *k "S." perlamellosus,* x ¾. *l, m "S." (Eospirifer) macropleura,* x ½. *n, o Strophonella leavenworthana,* x ¾. *p Trematospira multistriata,* x ¾. *q Actinopteria communis,* x ¾. *r Platyceras ventricosum. s P. spirale,* x ½. *t Phacops logani,* x ¾. *u Dalmanites pleuroptyx,* x ½.

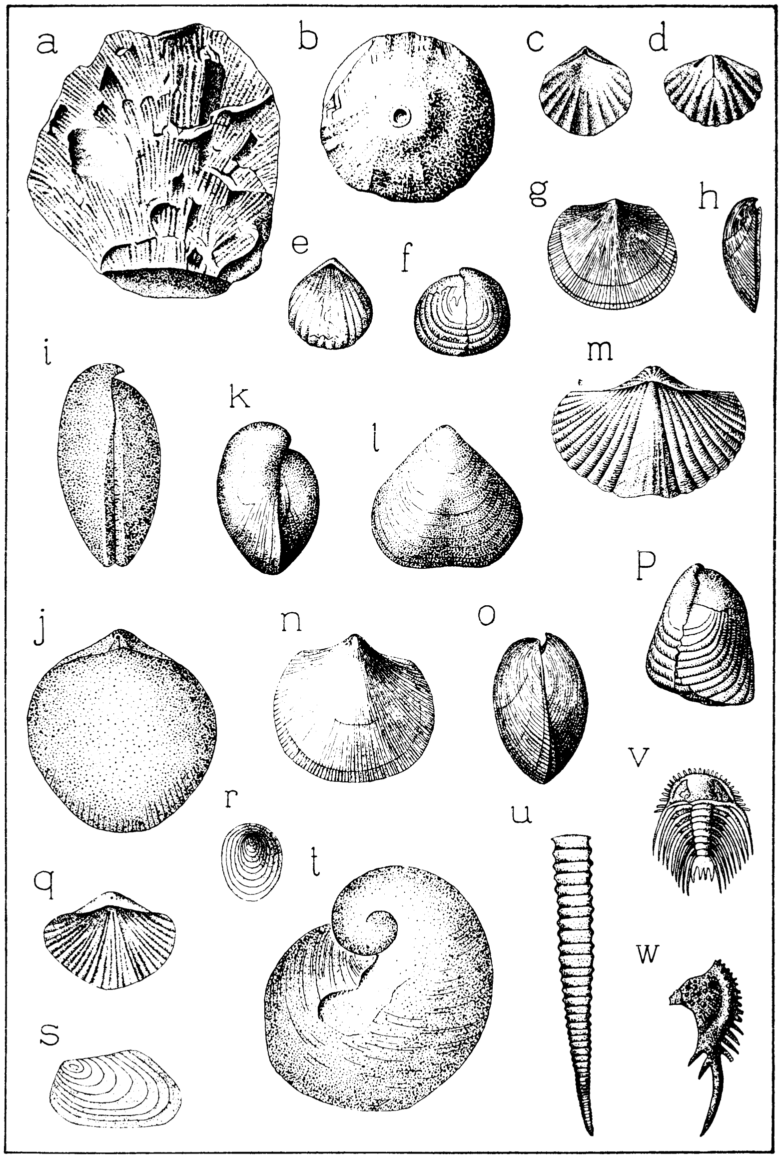

Figure 33 Becraft, Alsen and Port Ewen limestone fossils. (Becraft only, *b, k, t;* Alsen, Port Ewen only, *a;* Port Ewen only, ***c, d, r, s, v, w.*** Bryozoan, *a;* crinoid, *b;* brachiopods, *c-r;* pelecypod, *s;* gastropod, *t;* pteropod, *u;* trilobite, *v, w*). *a Monotrypa tabulata. b Aspidocrinus scutelliformis. c, d Anoplotheca concava. e, f Wilsonia ventricosa. g, h Platyorthis planoconvexa. i, j Rensselaeria* [*Beachia*] *suessana. k Gypidula pseudogaleata,* x ¾. *l Meristella arcuata,* x ¾. *m "Spirifer" concinnus,* x ¾. *n, o Schizophoria multistriata. p Uncinulus campbellanus,* x ¾. *q Trematospira perforata. r Pholidops ovata. s Cypricardinia lamellosa. t Strophostylus fitchi,* x ½. *u Tentaculites elongatus. v, w Acidaspis tuberculata;* right cheek enlarged. (*See* New Scotland plates)

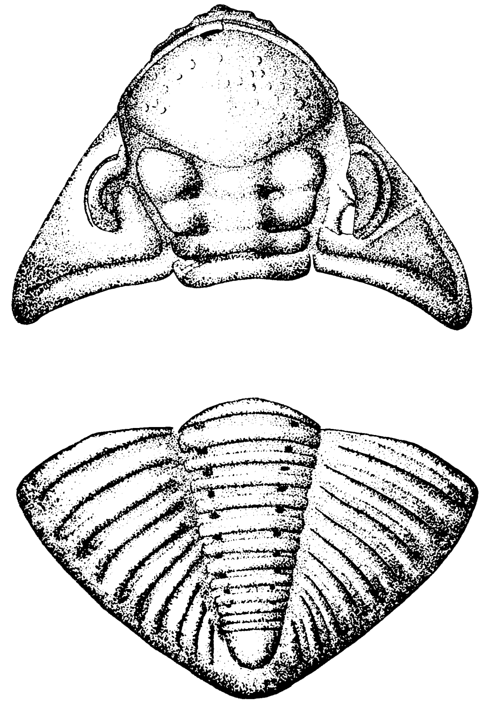

Figure 35 *Synphoria stemmata* Clarke, x ¾. Head and pygidium of trilobite from the Glenerie limestone. (After Clarke)

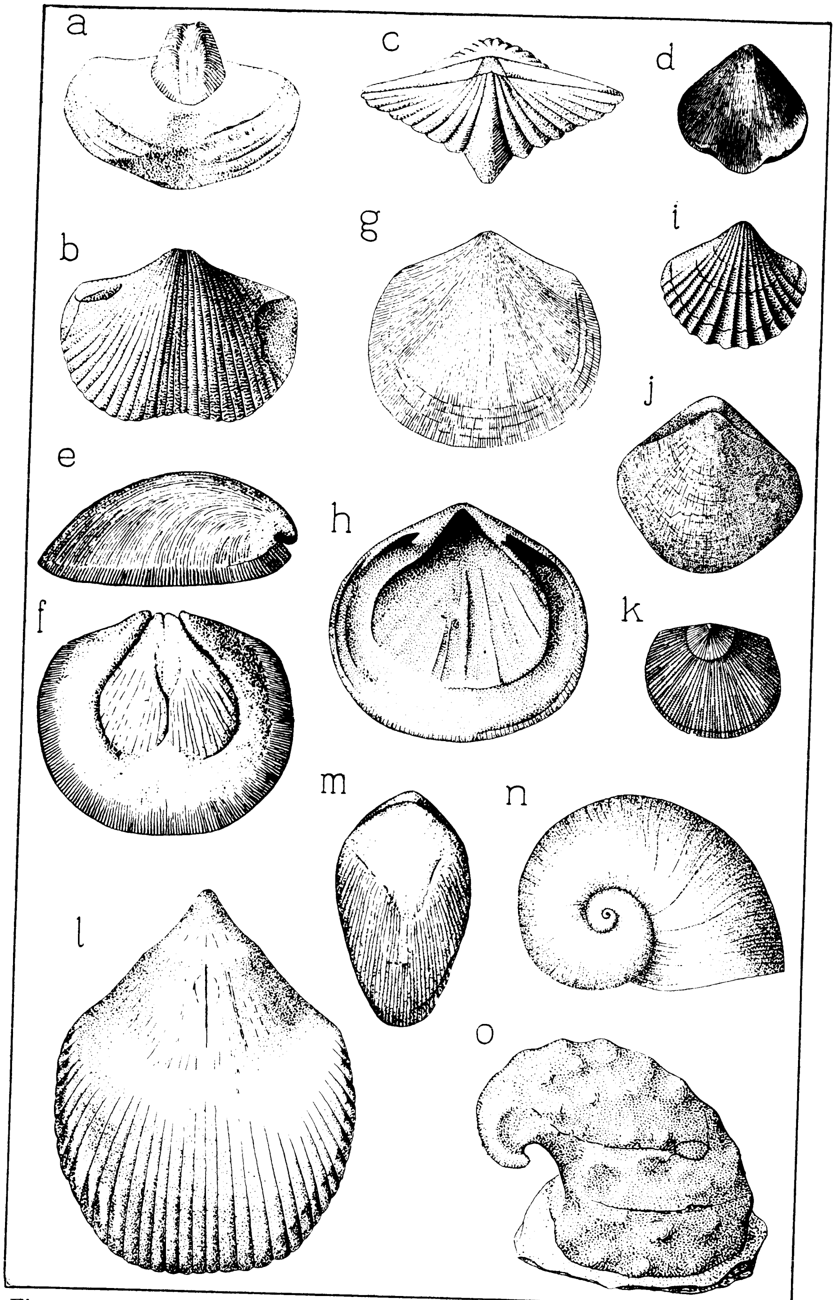

Figure 36 Oriskany sandstone and Glenerie limestone fossils. (Brachiopods, *a-m;* gastropods, *n, o*). *a, b "Spirifer" arenosus,* x ½. *c "S." murchisoni,* x ¾. *d Eatonia peculiaris. e, f Hipparionyx proximus,* x ½. *g, h Rhipidomella musculosa. i Leptocoelia (Anoplotheca) flabellites. j Meristella lata,* x ¾. *k Schuchertella becraftensis. l Straelenia [Plethorhyncha] barrandii,* x ¾. *m Rensselaeria ovoides,* x ½. *n Platyceras gebhardi,* x ¾. *o P. nodosum,* x ½.

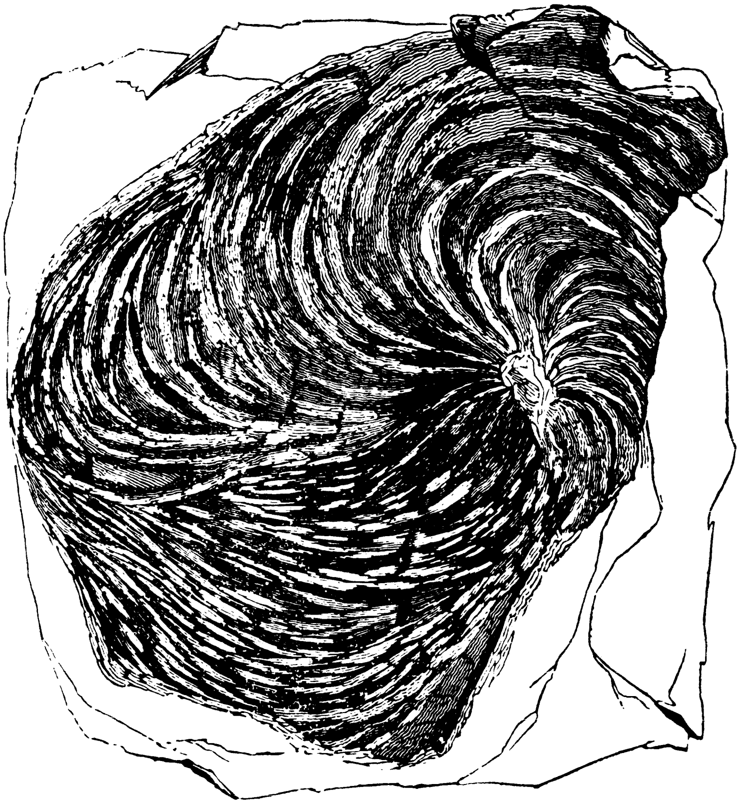

Figure 37 Esopus shale fossil. The worm burrow or "Cocktail", *Taonurus cauda-galli* (Vanuxem).

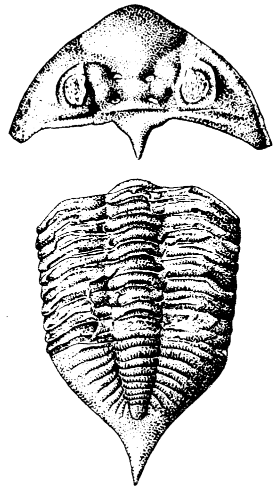

Figure 39 *Synphoria anchiops* (Green), x ½. A trilobite occurring in the Schoharie and Onondaga limestones.

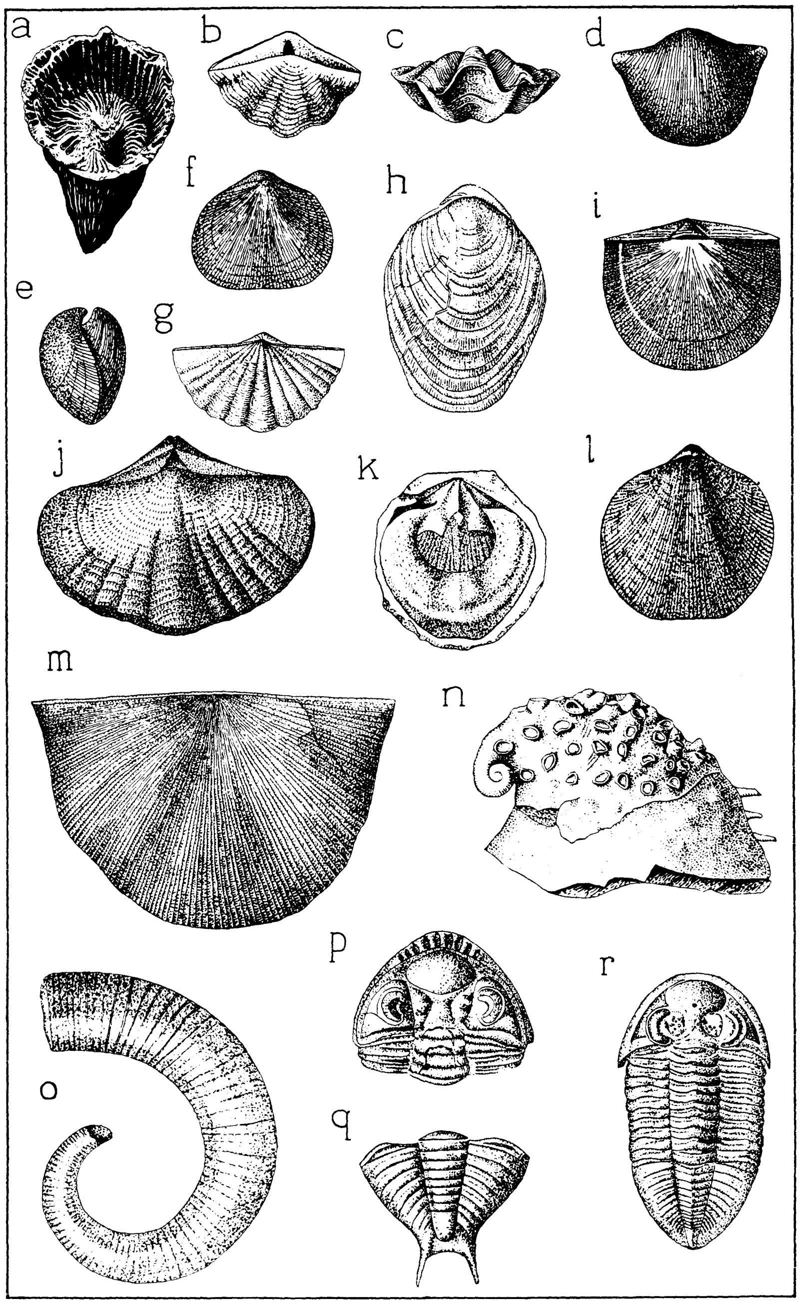

Figure 43 Schoharie and Onondaga limestone fossils. (Coral, *a;* brachiopods, *b-m;* gastropod, *n;* cephalopod, *o;* trilobites, *p-r.*) *a Zaphrentis prolifica,* x ½. *b, c "Spirifer" raricosta,* x ¾. *d Chonetes hemisphericus,* x ¾. *e, f Schizophoria propinqua,* x ¾. *g "Spirifer" duodenarius,* x ¾. *h Amphigenia elongata,* x ½. *i Schuchertella pandora,* x ¾. *j Elytha fimbriata. k, l Atrypa impressa,* x ¾. *m Strophonella ampla,* x ¾. *n Platyceras dumosum,* x ¾. *o Ryticeras trivolve,* x ⅓. *p, q Odontocephalus selenurus,* x ¾. *r Calymene calypso,* x ½.

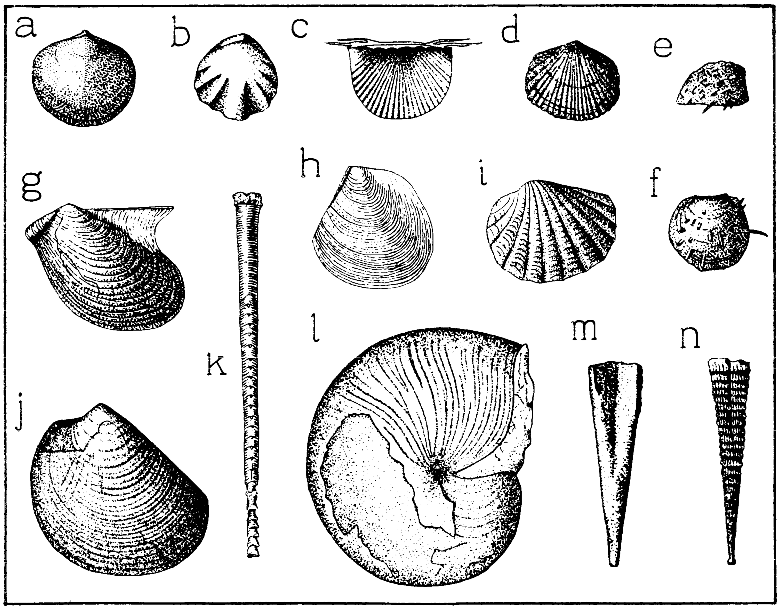

Figure 44 Bakoven shale fossils. (Brachiopods, *a-f;* pelecypods, *g-j;* cephalopods, *k, l;* pteropods, *m, n*). *a Nucleospira concinna,* x ¾. *b Leiorhynchus mysia. c Chonetes mucronatus,* x ¾. *d Leiorhynchus limitare. e, f Strophalosia truncata,* x ¾. *g Leiopteria laevis,* x 2. *h Pterochaenia fragilis. i Glyptocardia speciosa. j Lunulicardium marcellense,* x ¾. *k Bactrites clavus,* x ½. *l Tornoceras* [*Parodoceras*] *discoideum,* x ¾. *m Styliolina fissurella,* x 6. *n Tentaculites gracilistriatus.*

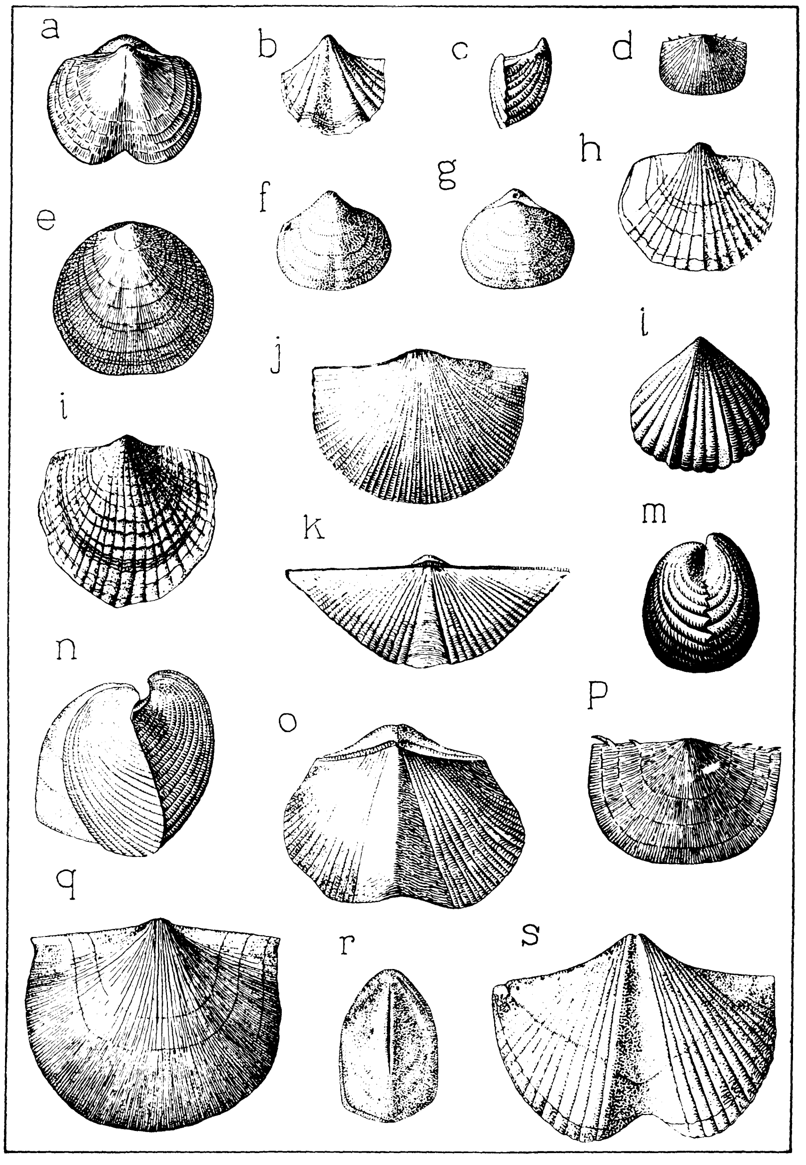

Figure 47 Mount Marion beds brachiopods. *a Schizophoria striatula*, x ¾. *b, c Cyrtina hamiltonensis. d Chonetes scitulus. e Rhipidomella vanuxemi. f, g Athyris cora. h Tropidoleptus carinatus*, x ¾. *i Atrypa spinosa*, x ¾. *j Stropheodonta inaequiradiata*, x ¾. *k "Spirifer" (Mucrospirifer) mucronatus*, x ¾. *l, m Camarotoechia congregata. n, o "Spirifer" (Paraspirifer) acuminatus, p Chonetes coronatus. q Stropheodonta demissa*, x ¾. *r Dignomia alveata*, x ¾. *s "Spirifer" (Spinocyrtia) granulosus*, x ¾.

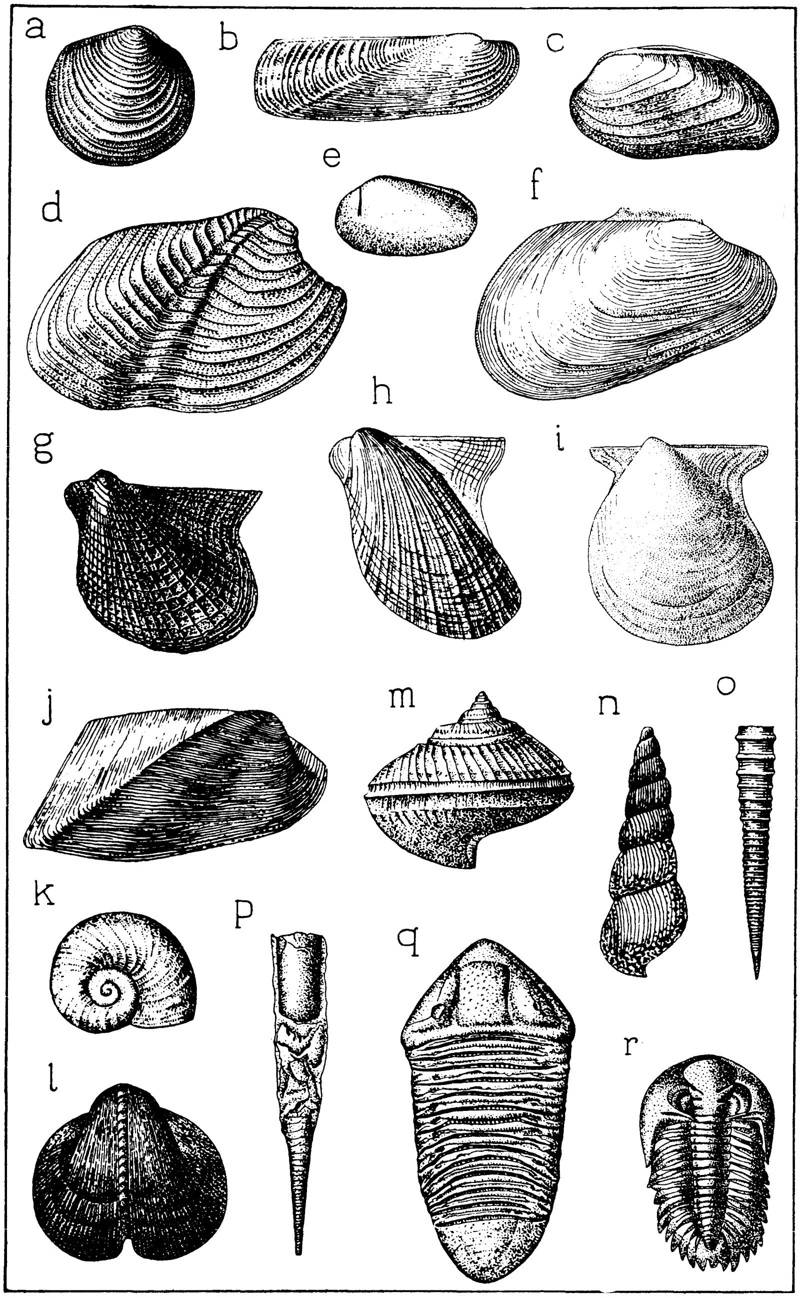

Figure 48 Mount Marion beds fossils. (Pelecypods, *a-j;* gastropods, *k-n;* pteropod, *o;* cephalopod, *p;* trilobites, *q. r.*) *a Paracyclas lirata,* x ¾. *b Orthonota undulata,* x ½. *c Nyassa arguta,* x ¾. *d Grammysia bisulcata,* x ¾. *e Nuculites oblongatus,* x ¾. *f Modiomorpha mytiloides,* x ½. *g Actinopteria boydi,* x ¾. *h Cornellites* [*"Pterinea"*] *flabellum,* x ½. *i Glyptodesma* (*Actinodesma*) *erectum,* x ½. *j Goniophora hamiltonensis,* x ¾. *k Diaphorostoma lineatum,* x ¾. *l Bucanopsis lyra. m Bembexia sulcomarginata,* x ¾. *n Loxonema hamiltonensis. o Tentaculites bellulus. p Michelinoceras?* [*Orthoceras*] *subulatum,* x ½. *q Homalonotus dekayi,* x ⅜. *Greenops* [*Cryphaeus*] *boothi,* x ¾.

Plate 1: Outcrop diagrams of roadcuts along Route 23 west of Catskill, New York. Diagrams with prefix 'N' are of the north side, and those with prefix 'S' are on the south side of the road.

Plate 2: Geologic map and sections of the fold-thrust belt in the region west of Catskill, New York. The map includes the Route 23 roadcuts, the Catskill Creek streamcuts.

Plate 3: Geologic map and sections of the fold-thrust belt in the region of Kingston, New York.

89-7385

Plate 1

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New York State Geological Survey
Robert H. Fakundiny, The State Geologist

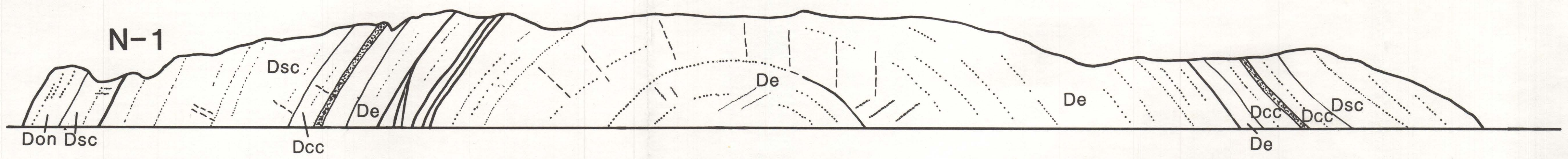
GEOLOGY OF THE ROUTE 23 ROADCUTS NEAR CATSKILL, NEW YORK

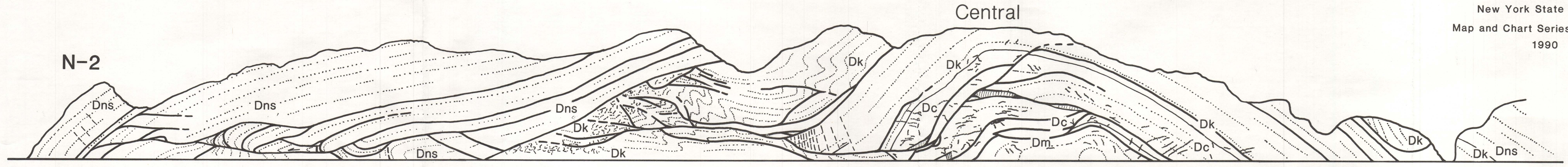
By Stephen Marshak

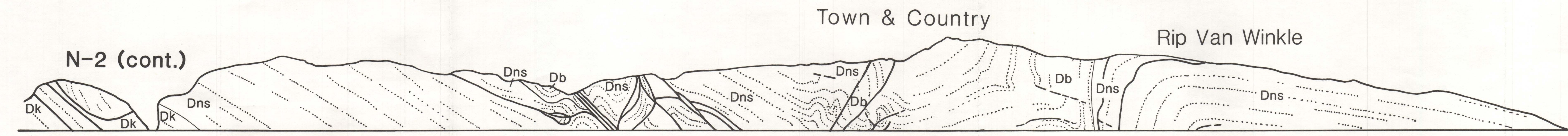
Geological Survey
New York State Museum
Map and Chart Series Number 41
1990

0 20
meters

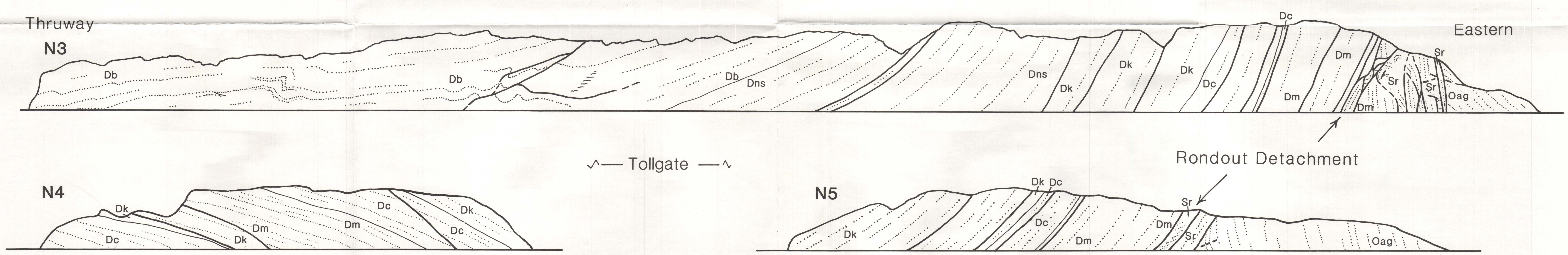
← WEST EAST →



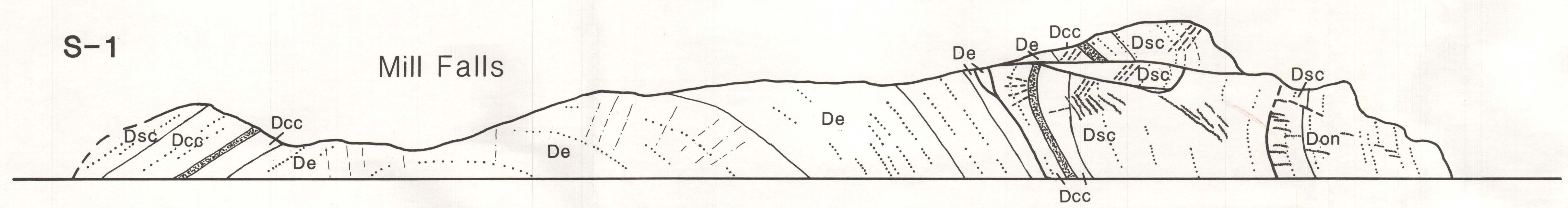


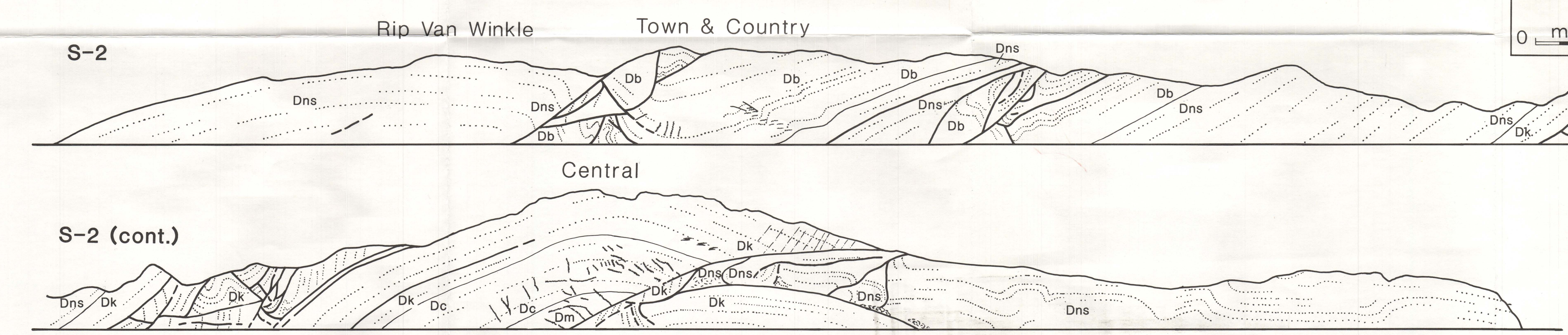


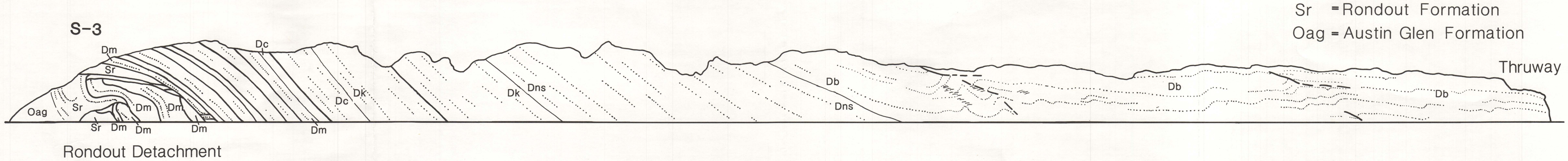
- Blocky Calcite
- Slip Surface
- Formation Contact
- Bedding Trace
- Cleavage Trace
- Vein Trace

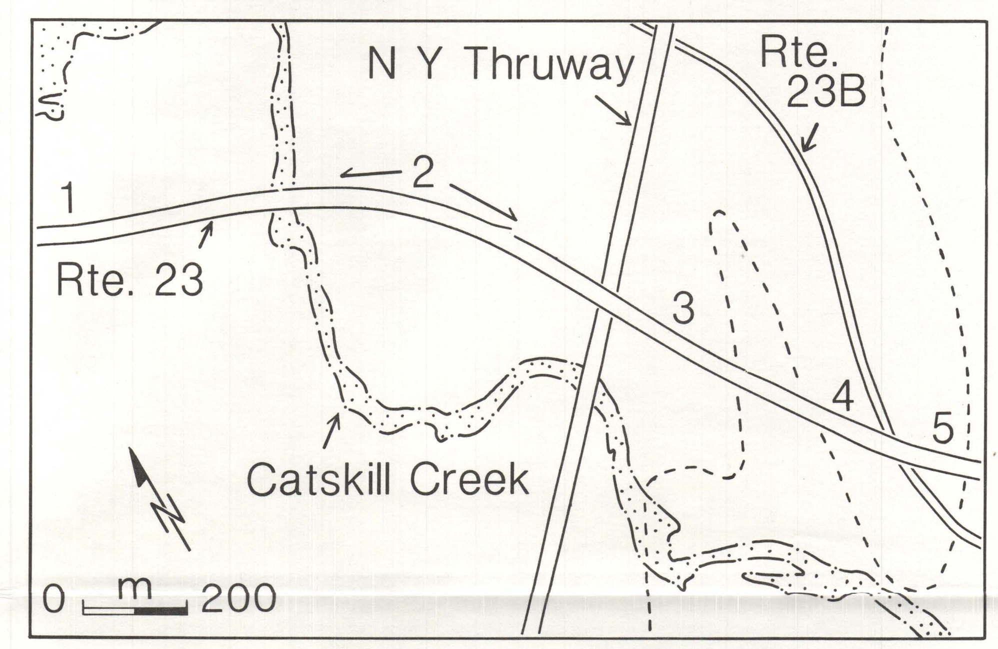


← EAST WEST →









Don	= Onondaga Limestone
Dsc	= Schoharie Formation
Dcc	= Carlisle Center Formation
De	= Esopus Formation
Db	= Becraft Limestone
Dns	= New Scotland Formation
Dk	= Kalkberg Formation
Dc	= Coeymans Formation
Dm	= Manlius Formation
Sr	= Rondout Formation
Oag	= Austin Glen Formation

Plate 2

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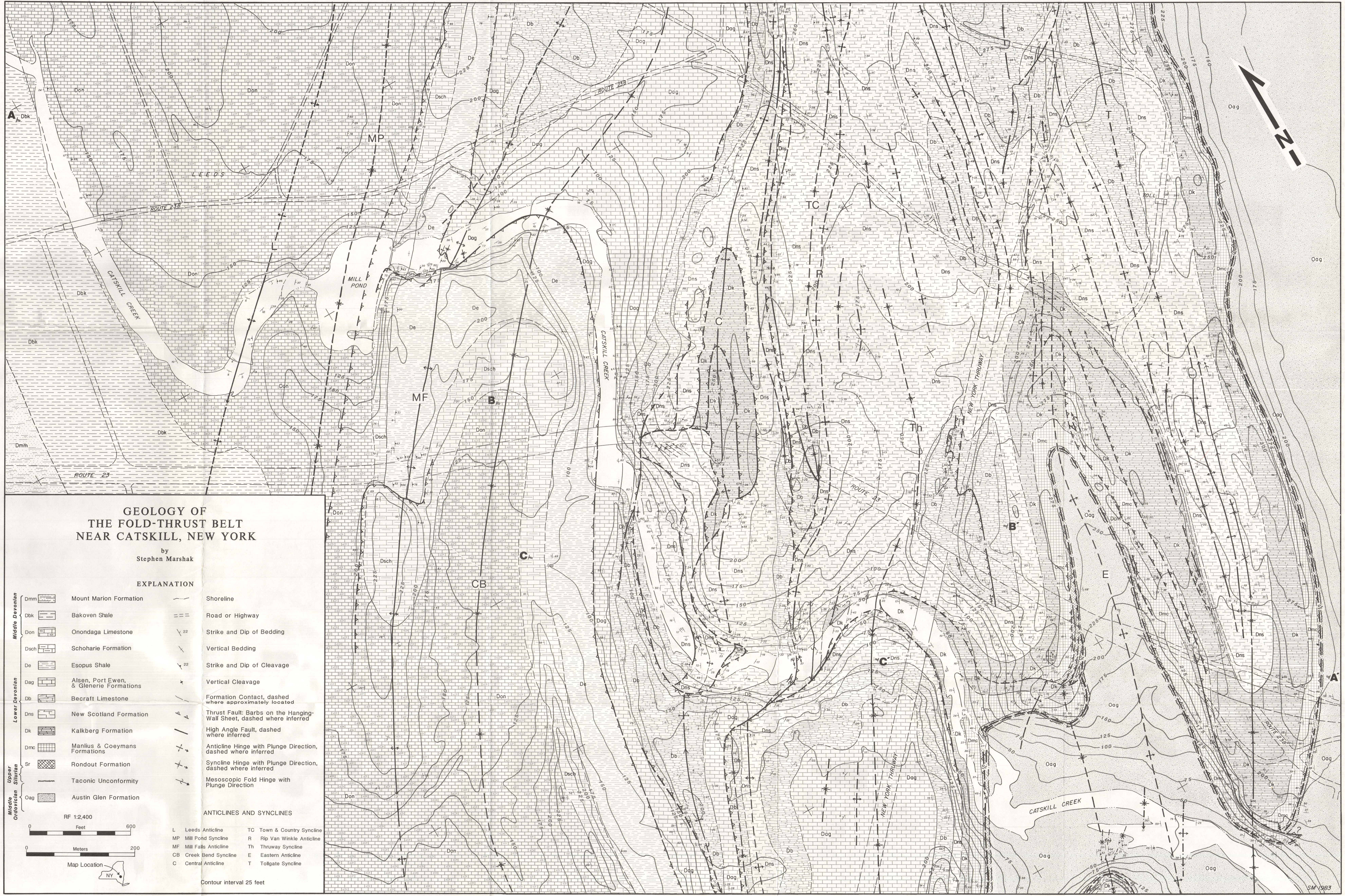
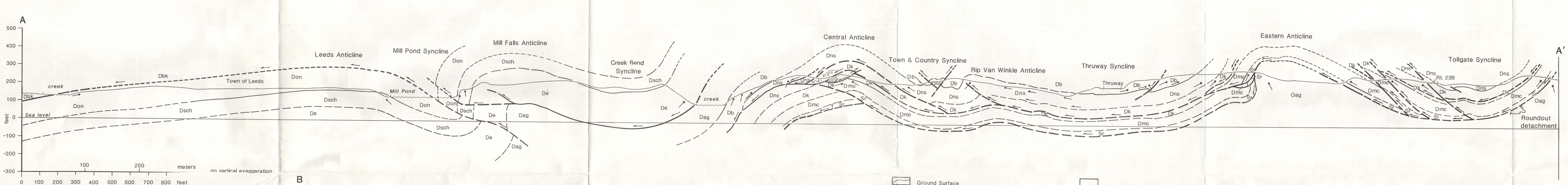
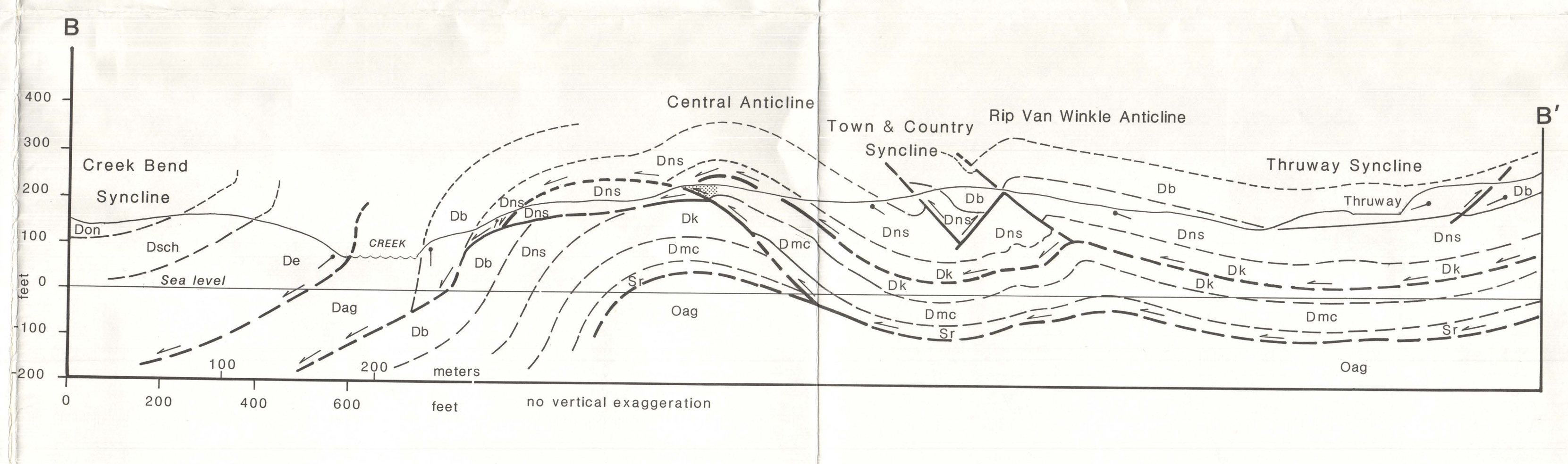






Ground Surface

Contact ; dashed where inferred

Fault ; dashed where inferred

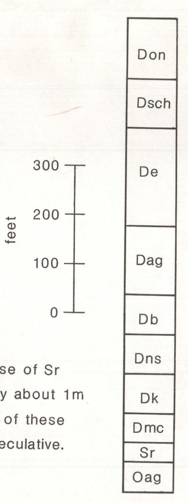
Bedding dip

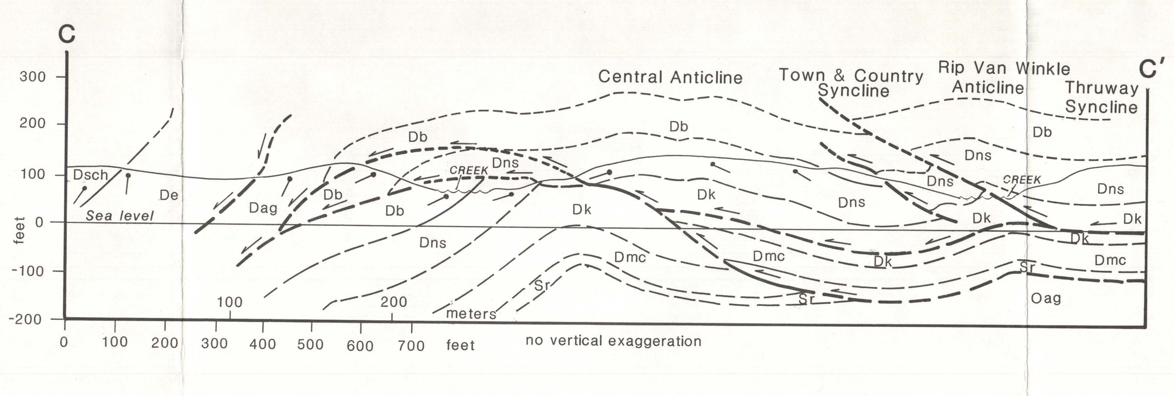
Mesoscopic folding

Cleavage

NOTE:

Roundout detachment is depicted at the base of Sr to avoid clutter. The detachment is actually about 1m above the actual unconformity in the area of these cross sections. Subsurface geometry is speculative.





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