Post-Alleghenian Deformation of the Shawangunk Ridge in NY and NJ

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INTRODUCTION

Studies of Appalachian foreland fold-thrust belt stratigraphy and structure and the internal massifs of southern New England indicate contrasting styles of Paleozoic orogenic deformation. The oldest of these, the Taconic orogeny of medial Ordovician age, produced continentward-vergent recumbent folding, dominantly low-angle ductile thrust faulting, with significant basement involvement along shallow east-dipping surfaces. The Middle Devonian Acadian orogeny produced layer-parallel, low-angle thrusts, upright to overturned folds as well as high-angle reverse faults. Younger, high-angle reverse faulting, continentward overturned folding with fault- truncated limbs are the result of the Late Paleozoic terminal phase of the Appalachian orogeny as indicated by post-"old Red" molasse facies layer-parallel faults, folds, and high- angle reverse faults in the Catskills, Bellvale Mountain, and High Falls, NY. and possibly in Newfoundland, NJ (Merguerian and Sanders 1991). Our preliminary field studies of the structural geology of the Shawangunk-Kittatinny ridge (Figure 1), a part of the Valley and Ridge Province in NY and NJ, suggest that the gentle west-dipping view of the geometry of the ridge is too simplistic and that changes in trend and structure of the ridge may be the result of post-Alleghenian (early Mesozoic?) strike-slip deformation.

PHYSIOGRAPHY

The Appalachian Valley and Ridge Province designates a subdivision within the Appalachian chain underlain by Paleozoic sedimentary rocks exposed in plunging anticlines and synclines. Deep erosion of these folded strata has created a pronounced linearity to the landscape consisting chiefly of elongate valleys and elongate ridges (Figure 2). Resistant formations, usually of sandstone, quartzite, or metaconglomerate underlie the ridges. Weaker formations, usually shales or carbonate rocks, underlie the valleys (Figure 3). Folds are not the only major geologic structural features found in this province; low-angle thrusts and high-angle faults are also present. The best place in northwestern New Jersey to see typical Appalachian Valley and Ridge-type landscape is in the Schunnemunk-Bellvale-Green Pond belt within the Highlands. In this belt are two thick, resistant, ridge-making formations: the Lower Silurian Green Pond Conglomerate and the Devonian Schunnemunk Conglomerate, which are separated by thick shale/siltstone units that form valleys. These strata have been folded on a large scale. Deep erosion of these folds has created a typical ridge-and-valley landscape (Merguerian and Sanders 1995a).

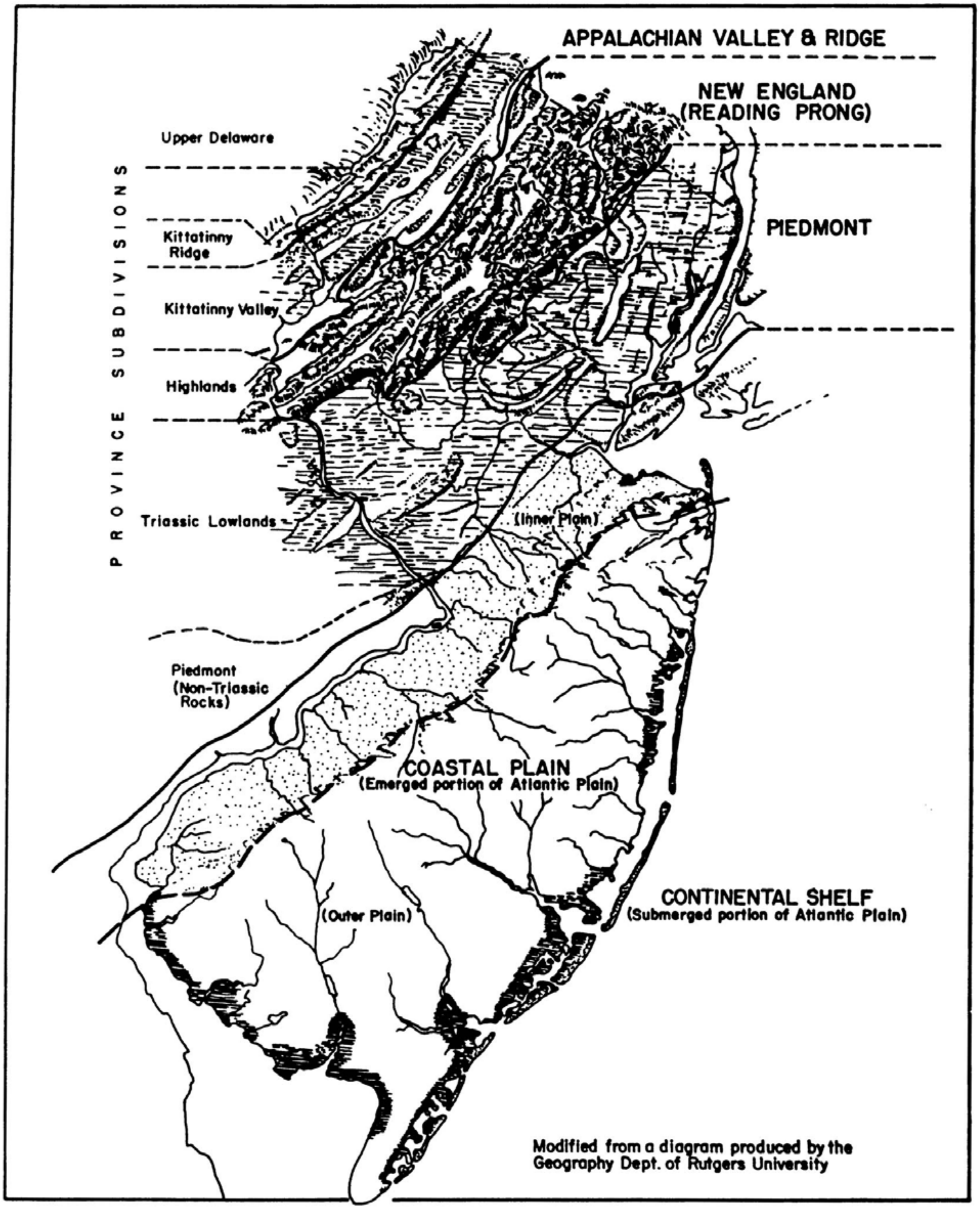

Figure 1 – Sketch map of physiographic provinces in NW New Jersey. (Widmer 1964.)

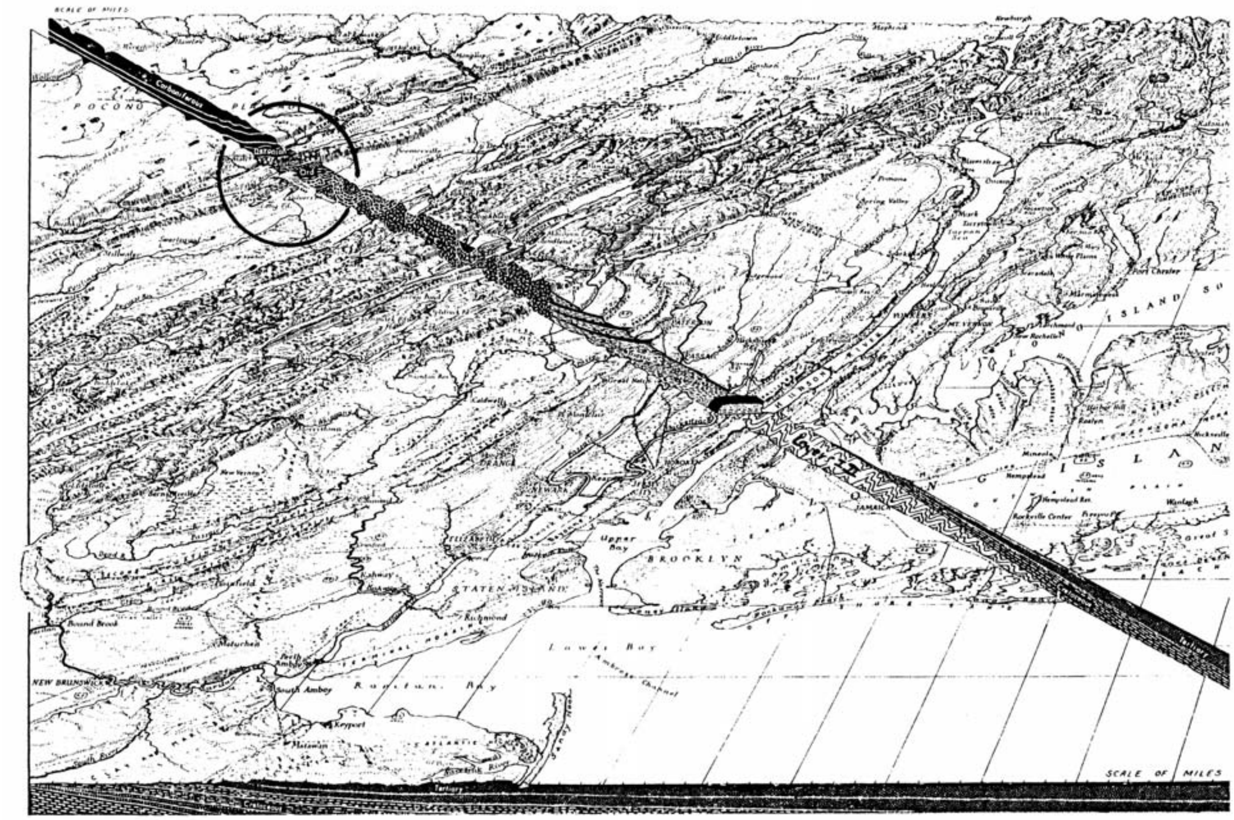

Figure 2 – Oblique bird's-eye-view physiographic diagram of the Appalachians, Newark Basin, and Atlantic Coastal Plain of NY and NJ with vertical slice oriented NW-SE to show geologic structure. Circled area shows the general west-tilted structure of the Kittatinny-Shawangunk ridge. (Erwin Raisz drawing.)

STRATIGRAPHY

Unlike metamorphic rocks of the Appalachian infrastructure, the rocks found northwest of the Hudson Highlands have been folded and faulted but have never been subjected to the temperatures that thoroughly recrystallize rocks. Throughout most of the Appalachian Great Valley, a general twofold subdivision of predominantly Sauk Sequence carbonates below and predominantly terrigenous rocks of the Tippecanoe Sequence above, can be recognized. These rocks were folded and eroded several times. Initially, the Sauk Sequence (Cambro-Ordovician) dolomitic carbonates were elevated and gently folded. During the Taconian orogeny, the folding was more intense and during subsequent uplift, erosion cut many formations. Accordingly, the unconformably overlying Lower Silurian Green Pond or Shawangunk Conglomerate rests on both Sauk and Tippecanoe units as well as Proterozoic basement (Finks and Raffoni 1989).

A notable feature of the terrigenous sediment, especially during the Early and Medial parts of the Silurian Period, was an enormous abundance of quartz, ranging in size from pebbles to silt. Although deep burial doubtless contributed to the dissolution of easily dissolved minerals, such as feldspar and carbonate, it is still remarkable that so much quartz of sand size and coarser was spread throughout such a vast area and to the thickness of many tens of meters. The sheet of Silurian sand extends unbroken from New York to Tennessee and has been found in the subsurface as far west as eastern Ohio. The Silurian strata also include dolomitic carbonates (a re-appearance of such rocks after the predominance of limestone during the Ordovician Period) and evaporites, notably halite rock (in the Salina Group). The details of the pattern of Silurian and Devonian environments of deposition are subjects of ongoing research.

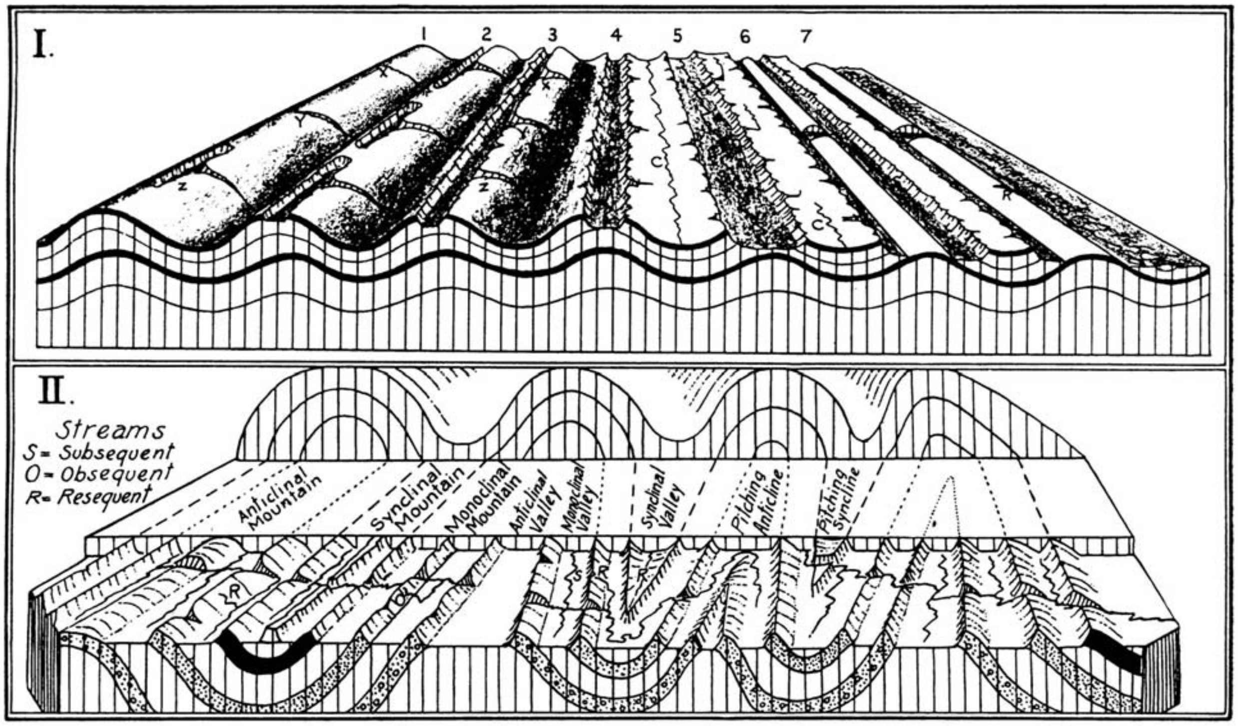

Figure 3 – Schematic block diagram through eroded anticlines and -synclines showing how resistant layers form linear ridges and weak layers, linear valleys. Upper diagram (I.) is after folding but before erosion and the lower diagram (II.) shows the effects of erosion of rocks of variable weathering resistance. The relationships shown here are common in the Appalachian Valley and Ridge Province of central Pennsylvania. (A. K. Lobeck, 1939, fig. on p. 588.)

STRUCTURAL GEOLOGY OF THE SHAWANGUNK KITTATINNY RIDGE

Forming an updraft that eagles, hawks, and butterflies follow along the entire Appalachian belt, the most-prominent unit of Valley and Ridge Province of NY and NJ is the ridge-making Shawangunk-Kittatinny Formation of Early Silurian age. This formation is part of an extensive sheet of coarse sand that spread westward from the Appalachians after the Taconic orogeny. Along the northwest side of the Appalachian Great Valley, this formation forms a wall-like ridge in which the strata dip to the NW (Figure 4). The younger strata share this direction of dip, but in the overlying rocks, the dip becomes less and less. Beneath the Catskill and Pocono plateaus, the strata are essentially horizontal. This NW dip grading northwest into horizontal strata has been taken by many to mean that the strike ridge marks the NW limit of deformation in the Appalachian chain. Granted the possibility of large-scale overthrusts of Late

Paleozoic age, then this NW dip may result from a ramp-related anticline and be the NW limb of such a structure (Figure 5).

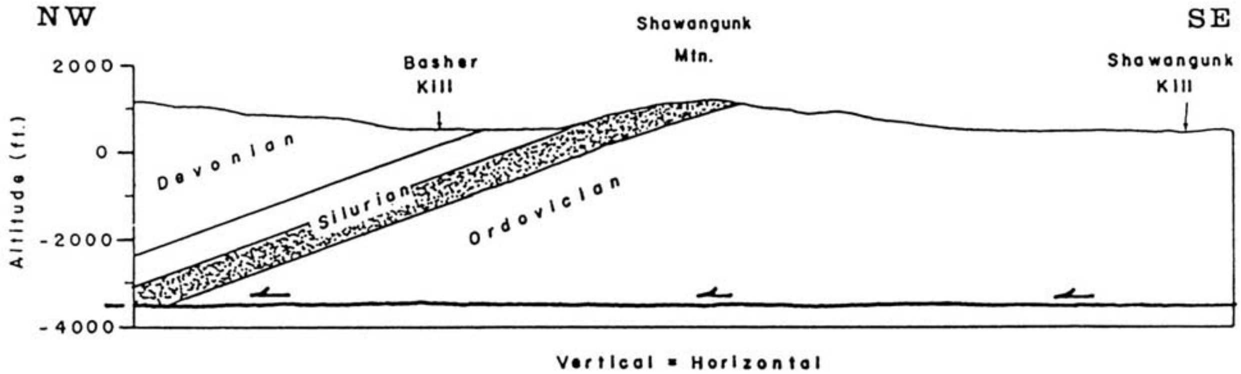

Figure 4 – Section based on seismic-reflection profile along US Route 17 in NY showing that NW dips of the Shawangunk Formation truncate against a horizontal reflector (Merguerian and Sanders 1995b).

AGES(S) OF PALEOZOIC OROGENIES

The rocks of the Appalachians have experienced at least three Paleozoic orogenic episodes. These were originally named Taconian (Medial Ordovician), Acadian (Medial Devonian), and Appalachian (Late Paleozoic). The last was viewed as the grandest of them all and its premier status signaled by the name of Appalachian Revolution. In 1957, H. P. Woodward proposed the interpretation that in the northern Appalachians, the last "significant" deformation had taken place in medial Devonian time. Moreover, Woodward (1957a, b) specifically rejected the "classical" viewpoint that the Appalachian "Revolution" (a supposedly terminal Appalachian event) marked the orogenic climax in the Appalachians. Woodward was convinced that the basis for the Appalachian "Revolution" lay somewhere between trivial and non-existent. He supplanted Appalachian with "Alleghenian" and "Revolution" with "disturbance." What has been happening since Woodward's proposal is that more and more evidence has been compiled to show that the Late Paleozoic deformation was considerably more vigorous than Woodward visualized. In other words, the "Alleghenian" has been upgraded.

No new data have changed the long-established geologic fact that the youngest deformed strata in northwestern New Jersey are of medial Devonian age (in the Schunnemunk-Bellvale-Green Pond belt). Therefore, the final deformation of the strata in the Valley and Ridge province could have occurred any time after the middle of the Devonian Period (Schuchert and Longwell, 1932, p. 323; Chadwick and Kay, 1933, p. 7; Rodgers, 1967b, p. 416). Indeed, folding of the Valley and Ridge along strike through NY, NJ, and PA must be the result of late Paleozoic deformation since Pennsylvanian and older rocks are involved in the deformation. Based on our preliminary studies in northwestern NJ and vicinity, we would like to advance the hypothesis that post-Paleozoic deformation is also recorded in the region. We see regional and local refolding of Valley and Ridge structures and see that the same deflection in strikes can be found in basin-filling strata of adjoining Mesozoic basins.

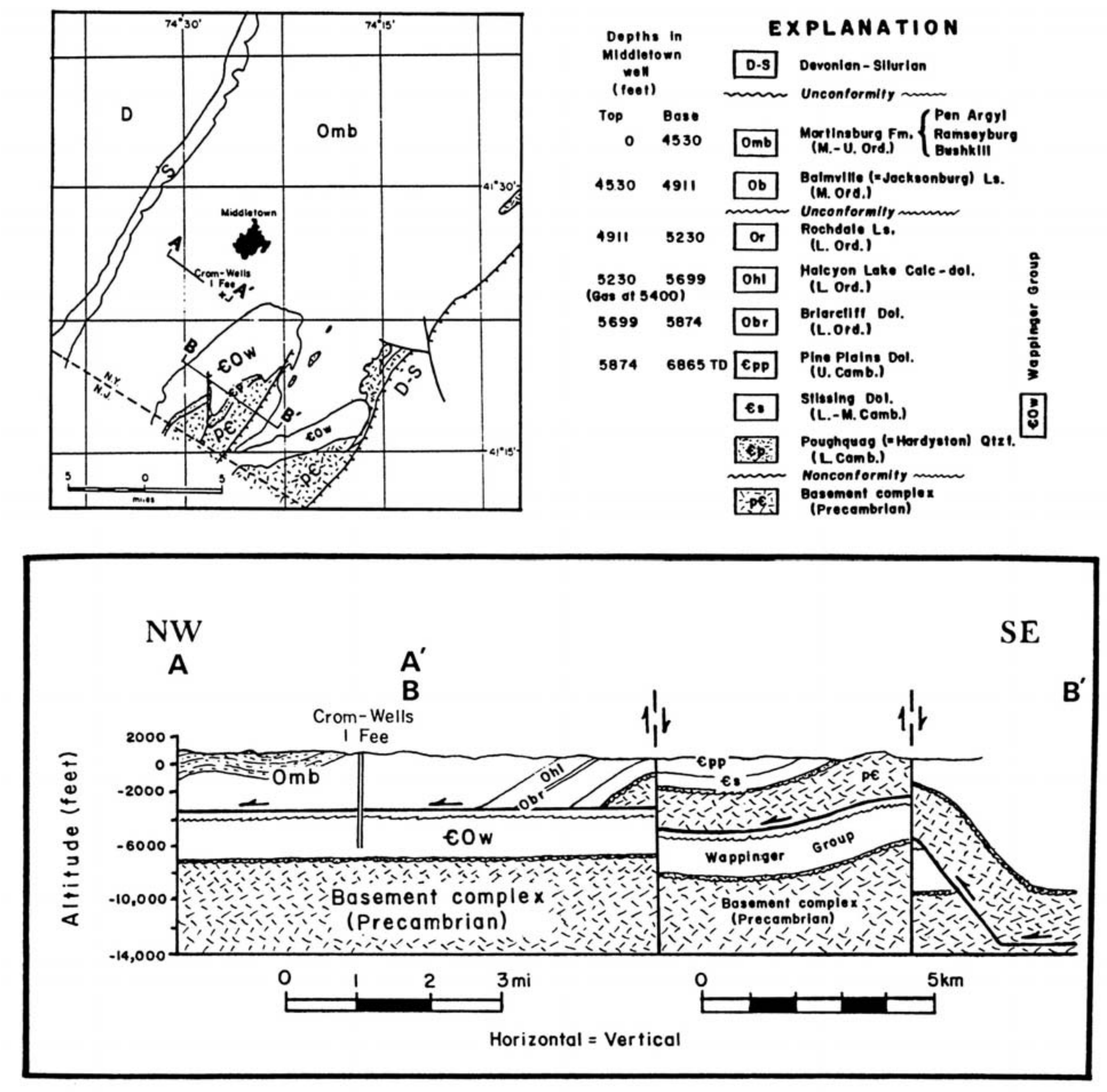

Figure 5 – Geologic setting of Middletown gas well (Crom-Wells 1 Fee), Orange County, NY.
a. Simplified geologic map showing locations of lines of sections AA' and BB'. (J. E. Sanders, 1983, fig. 3, p. 173, after New York State Geologic Map, 1970, Lower Hudson Sheet.)
b. Explanation of geologic map and sections including depths of formation boundaries in Middletown well (depths from Warthin and Pack, 1956 ms., in Offield, 1967). (J. E. Sanders, 1983, fig. 4, p. 174.)
c. JES interpretation of structure along lines AA' and BB.' Contacts of formations at surface from Offield (1967), but with subsurface relationships changed to show one possible arrangement according to overthrust interpretation. (J. E. Sanders, 1983, fig. 8, p. 176.).

At the Sunrise Mountain location of High Point State Park in northwestern New Jersey (UTM Coordinates: 523.35E, 4562.77N; Branchville 7-1/2' quadrangle), the Shawangunk-Kittatinny Conglomerate is exposed. By climbing down the eastern edge of the Shawangunk-Kittatinny escarpment during a Fall 2004 structural geology field trip to this area, Merguerian and students recorded an important observation. Here, the bedding changed rapidly from typical NE strike and gentle NW dip recorded elsewhere in the region. As a result of folding, the bedding changed trend to ENE and the dips varied to subvertical and overturned. We measured a maximum overturned deviation to N84°E, 74°SE. We found the reason for this deflection and curling up of the strata in the form of localized concentric folds. The folds plunge 29° into S75°W and we measured the axial surface at N50°E, 52°NW (Figure 6). Bedding plane slip lines are corrugated about the fold axes but trend roughly 72° into S35°E.

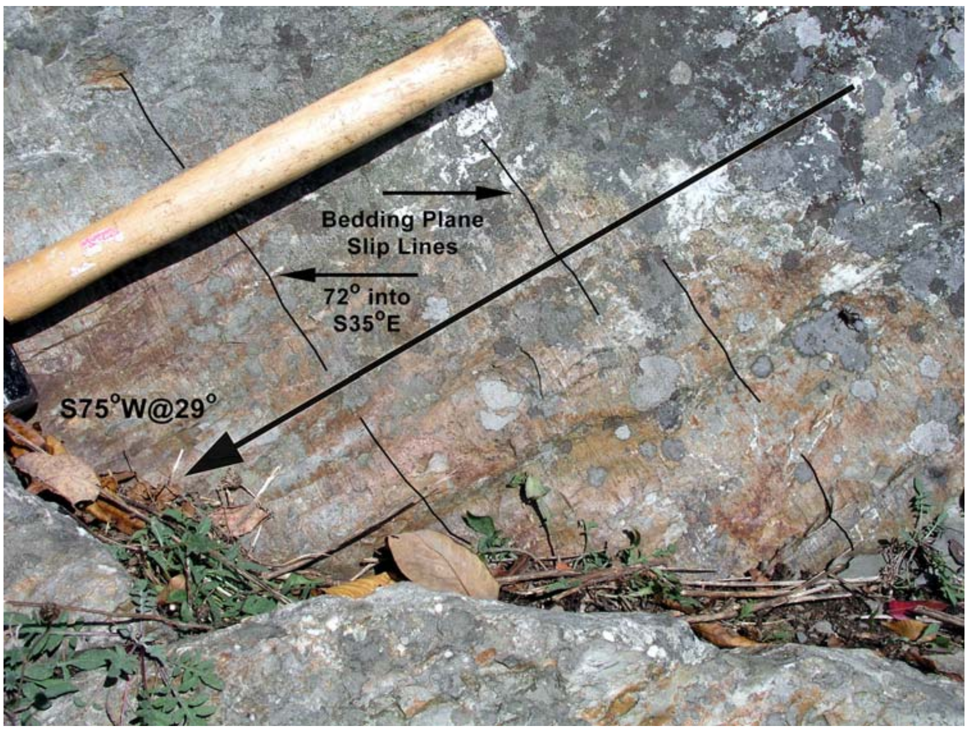

Figure 6 – Digital image of SW subvertical bedding and SW-plunging concentric folds at the eastern escarpment of the Kittatinny-Shawangunk ridge at Sunrise Point in High Point State Park, NJ. Note the corrugated overturned bedding that dips toward viewer and trends N84°E, 74°SE. Outlined in black are the hingelines of SW-plunging concentric folds and bedding plane slip lines perpendicular to fold axes.

The average trend of Kittatinny Mountain and most of the surrounding ranges and beds is about N45°E with NW dips, thus the 40° eastward divergence in strike and overturning of the Silurian strata is especially noteworthy. WSW-plunging concentric folds with NW dipping axial surfaces and SE plunging slip lines could have been produced by right-lateral shearing and we suggest that such shearing may be related to oroclinal bending of the entire Appalachian belt, as best exemplified to the south in Pennsylvania. Taken together, the Newark, Gettysburg, and Culpepper basins are distributed in a broad Z-fold and show geometrically similar oroclinal bending as does the Pennsylvania Valley and Ridge section of the Appalachians and the overall distribution of Proterozoic, Paleozoic, and Mesozoic strata (Figure 7). Such map relationships force us to suggest that post-Newark (mid-Jurassic?) deformation has been recorded. Geometrically, right-lateral shearing along the typical Appalachian trend (N45°E) may have caused the observed map-scale deformation of the Newark strata and oroclinal bending of the Appalachian chain in Pennsylvania and to a smaller degree at Sunrise Mountain in NW New Jersey. Right-lateral shearing could have produced the overturned folds found at Sunrise Mountain and would explain the marked change in trend recorded along strike from NJ northward into NY. (See Figure 7.)

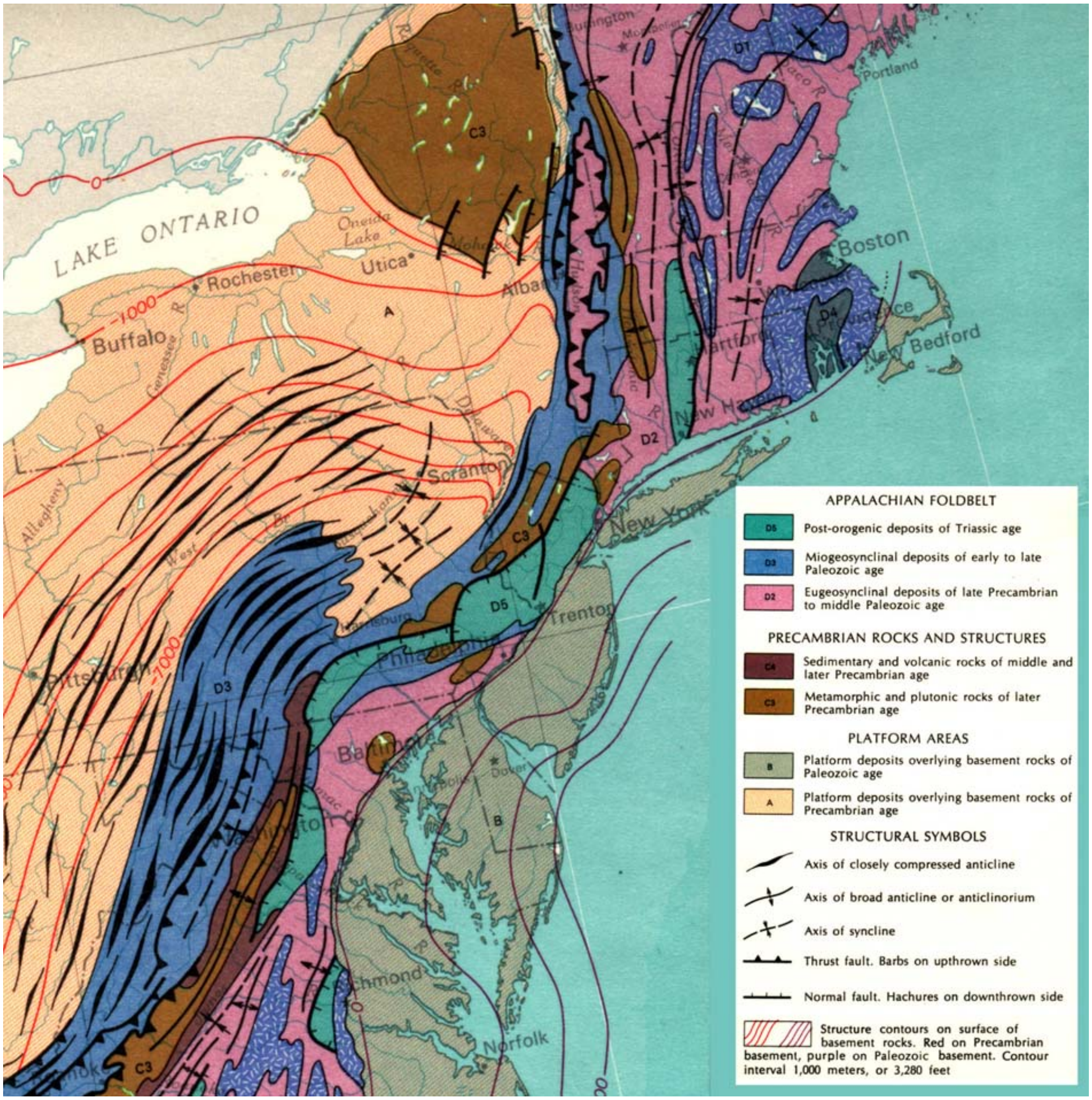

Figure 7 – Regional sketchmap showing the regional changes in trend for Proterozoic (C3 and C4 - Brownish), Paleozoic miogeosynclinal strata (D3 - Blue) and Mesozoic rift strata (D5 - Green) in the central and northern Appalachians. Note that all three tectonic elements display the same Z-shaped symmetry through PA, NJ, and NY. (Base map from National Atlas, U.S. Geological Survey.)

We are not alone in our suggestion that right lateral shearing has affected rocks of the NJ-NY vicinity. Flower structures (Harding 1985), present along the SE side of the Reservoir fault zone along the border of the western belt of the Green Pond outlier in NW New Jersey, has been inferred to display significant right-lateral strike-slip movement. Latest movement on the Reservoir Fault has been inferred to be of Late Paleozoic age, although the age constraints listed range from post-Medial Devonian to Triassic (Malizzi and Gates, 1989).

Interestingly, during the same time period that we would like to invoke right-lateral strike slip shearing along the east coast of North America to explain our observations, two important large-scale events were taking place on either side of the North American continent. Along the east coast of North America, incipient continental rifting began fracturing the continent and ultimately led to the formation of Mesozoic basins. These basins filled with over 7 km of terrestrial strata before the initiation of active North Atlantic sea-floor spreading. According to Merguerian and Sanders (1994), post-Newark (mid-Jurassic?) folds and faults record a chanegeover to post-depositional compressive tectonics in the Newark basin, in what had previously been interpreted as a purely extensional regime. Along the western Cordillera, a late Triassic megashear truncated Permo-Triassic Sonoman belts and paved the way for early- to mid Jurassic subduction that resulted in compressive tectonics of the Nevadan orogeny. Based on paleomagnetic projections of Harrison and Lindh (1982) and Scotese et al (1984), during this period North America rotated and rose to higher paleolatitudes. The wild swings in early Mesozoic paleomagnetic pole positions for the North American continent (May and Butler 1986) suggest an active, accelerating continent. The combination of active tectonism along the western Cordillera (Schweickert, Merguerian, and Bogen 1988) and the opening of the North Atlantic (Manspeiser 1980) might have combined to create a mid-Jurassic changeover to compressive tectonics and right-lateral shear along the east coast of North America.

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